PRINCIPLES OF GREEN DESIGN: DEVELOPING A FRAMEWORK FOR PRODUCT TESTING

A Thesis

by

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ABSTRACT

A problem exists that many eco-friendly products on the market today are not widely accepted by consumers. Three pilot experiments were conducted to examine a few causes of poor eco-friendly product acceptance. The first two experiments involved the testing of alternative products to disposable plastic water bottles. Two hypotheses were developed- the attitude hypothesis and the user activity hypothesis. The attitude hypothesis states that a person with a positive environmental attitude will lead to better eco-friendly product recommendation and rating, greater product uses, and a greater chance of continued use. The user activity hypothesis states that a product with difficult set-up or cleaning will lead to a worse product recommendation and rating, fewer product uses, and a smaller chance of continued use. Participants took home a product to test for one week and then returned to complete two surveys- a demographics survey and a product evaluation survey. These surveys measured variables such as environmental attitude, product recommendation and rating, number of uses, continued use, and many others.

The results of the experiments show a relation between environmental attitude and the participants' future usage with the eco-friendly product. In addition, the data shows that difficulty of product set-up and cleaning relate to the users' opinion of the product. Since this methodology of testing has not been documented before, the lessons learned from these pilot experiments will help to develop a framework for product testing with human

subjects. The third pilot experiment tests the design method of defaults, which may be a powerful tool when designing eco-friendly products. The theory behind the default option is that people typically choose the default setting on a product, regardless if it is the best option. This theory was tested with the use of automatic paper towel dispensers. The lengths of the paper towels that the machines dispensed were changed periodically and the paper towel usage was measured. The results from this experiment indicate that users obey the rule of defaults, unless their needs are not being met at an extreme level.

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CHAPTER I

INTRODUCTION

The care of our environment is an ever-growing topic among people today and some choose to act upon this concern, while others choose to remain doubtful. Whatever the case may be, the push for a more environmentally conscious future is evident everywhere. Buildings are made with the environment in mind, environmental standards are becoming increasingly strict, and eco-friendly alternatives to products are more widely available to consumers. A certain pressure has been put on designers to produce products that are friendlier to the environment we all live in. This added design constraint can present quite a problem for designers, and many times it is overlooked by companies wishing to increase profits and cut out unnecessary costs. Sauer and Ruttinger (2000) also comment that, “While environmental friendliness of a product alone is certainly no guarantee for commercial success, research has indicated that ecological criteria are important to the decision-making process of consumers.” It is important for designers to understand that they can make a substantial difference in the world by considering the environment. Fuad- Luke (2004) expresses the importance of designers by claiming, “Designers actually have more potential to slow environmental degradation than economists, politicians, businesses and even environmentalists.”

It is true that designers have a great opportunity to make a difference, but in order to do so they must know the psychology behind people and their interactions with the environment. Environmental psychology is a large researched area and is quite complex. The factors that may influence or obstruct a person to behave in a pro-environmental way are complicated and hard to identify (Darnton 2004, Kollmuss and Agyeman 2002, Stern 2000). Many psychologists have tried to develop models to describe these factors and some have even created a process to change a person's poor environmental habits to pro-environmental behaviors (Darnton 2004, Kollmuss and Agyeman 2002, Stern 2000, Dahlstrand and Biel 1997, Swim et al. 2009). A brief background behind environmental psychology is presented here along with the relevant research pertaining to design for the environment.

Environmental psychology

The study of environmental psychology is an important research topic within the field of psychology and deals with the interactions between people and their environment. It has been a widely researched topic, but only recently has this science been applied to engineering design. The problem exists that eco-friendly products are still not widely accepted, and this could be because of many reasons. A large part of the problem is that people have many psychological barriers that prevent them in taking the necessary steps to do things like recycle, use alternative forms of transportation, and use more environmentally friendly product alternatives. People are unaware of the problem, unsure what to do, do not trust experts on climate change, think the problem does not apply to them, are fixed in their ways, or believe that their actions will not make a difference (Swim et al. 2011). Psychologists have begun to research this interface between psychology and climate change so that these psychological barriers can be identified and broken down (Darnton 2004, Swim et al. 2011). In order for a person to lead a more eco-friendly life, they must learn to break their environment damaging habits and change their behaviors for the betterment of our environment.

The motivation to change behaviors can be influenced by many psychological drivers such as needs, wants, goals, values, ideologies, beliefs, attitudes, worldviews, perceptions of prescriptive and cultural norms, and identification to nature (Swim et al. 2011). A very large amount of research addresses influencers of pro-environmental behavior and there has been debate over whether a positive environmental attitude leads to pro-environmental behaviors. One side claims that people who have pro-environmental attitudes will thus exhibit pro-environmental behaviors such as recycling and using eco-friendly products. Therefore, to create more eco-conscious people in the world, we should attempt to change their attitude toward the environment. This theory seems very logical, however research points to the fact that largely this is not the case (Kollmuss and Agyeman 2002).

A more popular belief opposes the idea that attitudes directly influence environmental behaviors. This theory claims that our attitudes are disconnected from our behaviors, especially when it comes to the environment. For example, a person may think they are an eco-conscious being, yet they do not practice recycling. Just because a person has the desire to be environmentally friendly does not mean they will actually perform the necessary actions to help save the planet. This is often referred to as the “value-action gap” (Darnton 2004). So if there is a gap between attitudes and behaviors, how do we get people to change their behaviors? Many theories attempt to explain this phenomenon and give solutions to fix the problem. A consistent idea found in literature is that people consider many factors when making decisions about their environmental behaviors. While environmental attitude may be one factor affecting our behavior, other factors may outweigh our attitudes toward the environment.

There have been numerous models that attempt to describe the disparity between environmental awareness and pro-environmental behavior. A piece of literature titled Mind the Gap by Kollmuss and Agyeman gives a summary of many of these models: early US linear progression models; altruism, empathy and pro-social models; and sociological models. In the early linear models, psychologists believed that environmental knowledge led to environmental attitude, which led to pro-environmental behavior. As discussed earlier, this idea was soon discredited. Ajzen and Fishbein (1980) developed this idea further by creating the theory of planned behavior, which claimed that attitudes influence intentions, which determine our reactions. They also concluded that our intentions are not only affected by our attitudes, but also by social pressures. In 1986, the Model of Responsible Environmental Behavior was published by Hines, Hungerford, and Tomera (1986) and gave many more factors that influence behavior. These six factors were knowledge of issues, knowledge of action strategies, locus of control, attitudes, verbal commitment, and individual sense of responsibility (Kollmuss and Agyeman 2002).

The altruism, empathy, and pro-social models also discuss environmental behavior but from a different perspective. The theory is that in order for a person to behave in pro-environmental ways, they must have a self-less personality and concentrate on the needs of the community. This theory also states that the people who already have satisfied their personal needs are more likely to display pro-environmental behaviors because they have more resources to focus on environmental issues. One theory developed by Stern (1993) describes three orientations that people have which influence their environmental concern. The egoistic orientation deals with removing the suffering from oneself, the social orientation deals with removing the suffering of others, and the biospheric orientation deals with removing suffering from the non-human world. He claims that every person has all three of these orientations to some extent. Stern concluded that the stronger the egoistic orientation a person has, the stronger the motivation toward the behavior. However, this is only the case when the pro-environmental behavior agrees with the person's needs and wants (Kollmuss and Agyeman 2002).

A sociological model developed by Fietkau and Kessel (1981) describes five factors that influence behavior. These factors include attitude and values, possibilities to act ecologically, behavioral incentives, perceived feedback about ecological behavior, and knowledge. Another theory developed by Blake (1999) takes into account the reasons why people do not act in pro-environmental ways and labels them as barriers. A few of these barriers include lack of interest, lack of responsibility, and lack of resources (Kollmuss and Agyeman 2002).

It can be concluded from these various theories and models that pro-environmental behavior is influenced by many factors. The psychology behind a person's decision-making is so complex and many times is not logical so it is difficult to explain exactly why a person behaves as they do. The models that have been described provide a good background to the influential factors behind environmental behaviors, but they do not explain how we should go about changing behaviors. There was a model developed by Dhalstrand and Biel (1997) that describes a systematic process to changing poor environmental habits to pro-environmental habits. Habitual barriers have been described as one of the most important obstacles to the mitigation of climate change impacts (Swim et al. 2011).

Dhalstrand and Biel describe a certain trade-off between a person's attitude and their habitual behaviors. If the habit is strong and well established, the attitude-behavior relationship is quite weak. In this case, any motivation or information aimed at this person to change their behavior will probably not be effective. If the habit is weaker, the motivation may be more effective in changing the habitual behavior. Dhalstrand and Biel propose a series of sub-steps in behavior change so a person with a strongly established habit that is detrimental to the environment may develop a new habit that is more beneficial to the environment.

The first step toward changing a poor habit is called activation, where the person realizes that our environment should be valued. This activation can be general such as we should try to look after the environment or it can be specific, such as we should recycle plastic bottles after use. A more specific activation has a greater impact on an individual. The second step in the process is attending present behavior where information about the person’s habit is addressed and their negative impact toward the environment is brought to their attention. The third step is to consider the alternative solutions so that the person knows about better choices that are more environmentally friendly. Planning the new behavior is the next step in the process so that the exact instructions to changing their behavior can be identified. The person can then test the new behavior and evaluate it in terms of mental and physical strain and in terms of monetary cost. The final step is establishment of a new behavior through repeated support of this changed habitual behavior (Dhalstrand and Biel 1997).

The results from Dhalstrand and Biel’s experiment demonstrated that an important first step in behavior change is to realize that we should be responsible for our actions and exhibit behaviors to protect the environment we live in. Once this realization is achieved, people may be more motivated in the processes of changing their behaviors. It was also found that when a new behavior is tested and evaluated, the specific beliefs relating to the product would determine whether a new pro-environmental behavior would form (Dhalstrand and Biel 1997).

The participants in this study were all college-age students, which is a very interesting group to examine for this type of research. College students may exhibit many of the psychological barriers described earlier, such as lack of resources, lack of interest, selfishness, and lack of knowledge about the environment. Since the majority of college students probably do not consider the environment as a priority in their behaviors, they represent a good subject pool for this research. It will be interesting to discover whether the participants actually change their habits and use more eco-friendly product alternatives.

Applying the information learned about environmental psychology to the world of product design may help lead to eco-friendly products that are more widely accepted by consumers. The following sections briefly describe research pertaining to design for behavior change.

Designing for behavior change

Today, a substantial opportunity exists for designers to make a positive environmental impact in the world. Many times, the most environmental damage occurs during the usage stage of a product’s life cycle as a result of poor user behaviors (Elias et al. 2009, Tang and Bhamra 2008, Lockton 2009a, Lilley 2009). Designers must really concentrate on the use stage during product development since many of the environmental impacts are determined there. Fortunately, research has shown that user behavior can be influenced through product design (Oberender et al. 2001). The goal for the designer should be to minimize the possibility for environmentally erroneous behavior and support pro-environmental behaviors. Sauer and Ruttinger (2000) argue that these poor behaviors during the use stage result from mismatches between the user, product, and task. A functional problem occurs between the task and product interaction so that the product does not contain the ecological features for the task. An efficiency problem exists between the user and the product because the user does not know how to operate an ecological feature on the product. The mismatch between the user and the task is known as the effectiveness problem, which means the user does not know how to perform a task in an ecological manner (Sauer and Ruttinger 2000). A possible tool to aid designers in eliminating these environmentally erroneous behaviors is the Design with Intent method.

The Design with Intent method (DwI) is a tool that aids designers in developing products that influence user behavior (Lockton et al. 2009a). This method is especially helpful in eco-friendly design because a designer can create a new product or improve an existing one so that it influences the user to behave in a pro-environmental way. This method incorporates many of the theories described by psychologists as well as people from many different backgrounds and translates them into applicable design techniques. The developers of this method saw a need to combine all the behavior change theories across many fields of research, interpret them, and display them to the designer so that they could easily understand and apply them. There are several "lenses" that correspond to the various views on behavior change so that the designer is presented with many different solutions to their problem. These lenses allow the designer to think of the problem from a different perspective than they are usually accustomed to, thus leading to a greater variety of solutions.

The designer can use the DwI method in either inspiration mode, or prescription mode. In inspiration mode, the method serves as a sort of creative trigger for the designer. The cards have illustrations to help the designer understand the pattern quickly and easily and then apply it to their design. In prescription mode, the designer can formulate the design problem in terms of the user's target behaviors. In the case of environmentally friendly product design, the target behavior might be to use less electricity or less water. This mode 'prescribes' a set patterns for the designer that are applicable to their problem (Lockton et al. 2009b).

Since the method's introduction at the Persuasive Technology Conference in 2008, the method has been further developed to include eight lenses: architectural, error proofing, interaction, ludic, perceptual, cognitive, Machiavellian, and security. Each of the lenses presents several design methods to influence behavior, such as hiding functions or elements under the architectural lens or using feedback through form with the interaction lens. There are currently 101 different Design with Intent cards that a designer can use that represent ideas and inspiration for behavior change. An example of one of the cards in the DwI method is shown below in Figure 1. The card is colored orange, which represents the interaction lens and the pattern is Real-time Feedback.

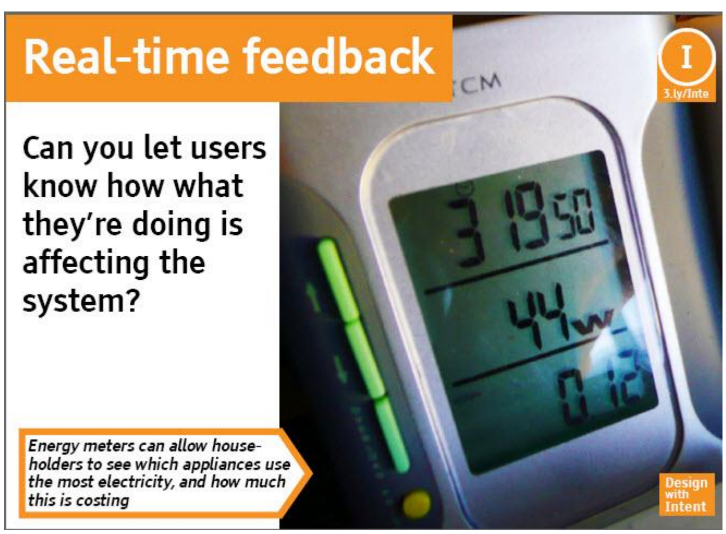

Figure 1. Example pattern of DwI method (Lockton et al. 2010).

The results of the experiments done in this research will help to create additional design techniques for eco-friendly product design. Based on the potential findings of this research, supplemental patterns may be added to the 101 cards that are already existing. In addition, the paper towel experiment presented in this research will actually test the validity of the Defaults pattern found in the DwI method.

Interaction design has become an important research topic in the world of environmental design and has mostly been incorporated in the computer science industry with Human-Computer Interaction, but is slowly being introduced to product design with Persuasive Technology. Here, the product-user interactions are studied so that the user's poor environmental behaviors can be identified. Once these behaviors are identified, the product designer can develop interfaces within the product to lessen the chance that these poor behaviors will occur. Oberender et al. (2001) illustrated this process through the redesign of a vacuum cleaner. First, the environmentally relevant erroneous behaviors were found using the error-types and error-causes-matrix as well as Eco-FMEA. A redesign of the vacuum cleaner was then developed so that it included a feedback device so that users would consume the minimum amount of electricity when vacuuming.

Another product that was developed to increase user awareness about electricity consumption is the Power aware cord. An important topic in eco-friendly product design is the awareness of electricity we use every day. Electricity is sometimes a hard concept to grasp for people, especially since we cannot see it. The creators of the Power Aware

Cord have developed a product that allows users visualize the electricity flow from their devices. The cord contains electroluminescent wires that glow when energy is passing through it and the intensity of the light changes as the amount of energy changes. The designers of this product hope that the visual feedback display of energy will help to change user's energy consumption behaviors (Gustafsson and Gyllensward 2005).

Design research has shown that energy losses in products are a result of both the technology and the user (Elias et al. 2009). At times, the user-related energy losses of a product can be a very large portion of the overall loss, but with certain design techniques, this can be minimized. According to Elias et al., there are three ways to reduce these user-related losses, which are improving consumer education, providing feedback, and User-Centered Eco-Design. The user-centered design strategy is used for creating new products and focuses on the user, their behaviors, and the product use or misuse.

Lilley (2009) also describes three approaches to influencing behaviors as Eco-feedback, behavior steering, and persuasive technology. The Eco-feedback strategy gives reminders to the user about their product use and allows the user to have the most power in decision-making. Behavior steering encourages the user to behave in certain ways and allows the user to have less power in decision-making and more power entrusted to the product. The persuasive technology approach designates the most power to the product in order to influence the user to change their behavior. Her research considers the user when exploring the effectiveness and acceptability of each of these methods. The level of user intervention is assumed to affect how well the user responds to desired behavior change. Lilly claims, “Finding an acceptable level of product influence through intervention and ensuring the moral acceptability of such interventions will be key to ensuring customer acceptance and manufacture buy-in” (Lilley 2009).

Measuring environmental concern

An important research question addressed in this experiment is whether a person’s attitude toward the environment is an indication of their pro-environmental behavior. In order to assess this question, the level of each participant’s environmental concern must be measured as accurately as possible. The two most frequently used scales for measuring environmental concern are the Ecological Attitude Scale or EAS (Maloney, Ward, and Braucht 1975) and the New Environmental Paradigm Scale or NEP (Dunlap *et al.* 2000). The EAS is used to measure environmental behavior and consists of three scales, the Verbal Commitment, the Actual Commitment , and the Affect. The VC measures what the person states they are willing to do to protect the environment, the AC measures what the person actually does to protect the environment, and the A measures the degree of emotion related to such issues (Maloney, Ward, and Braucht 1975). The NEP scale was originally developed in 1978 by Riley E. Dunlap and Kent D. Van Liere and consisted of 12 Likert items to measure environmental attitude. The scale was later revised in 2000 to consist of 15 items. The NEP addresses five different ecological worldview facets: the reality of limits to growth, antianthropocentrism, the fragility of nature’s balance, rejection of exemptionalism, and the possibility of an ecocrisis (Dunlap *et al.* 2000). Both the EAS and the NEP will be used in this study to measure attitude and behavior.

Research outline

Three pilot experiments will be performed to address various aspects of eco-friendly design. The first pilot experiment will be referred to as the "initial pilot experiment" in the following sections, while the second pilot experiment will be called the "consistent bottle experiment", and the third pilot is called the "paper towel experiment". One purpose of this research is to identify the variables that relate to the acceptance of eco-friendly products. The first two pilot experiments test two hypotheses:

1. A*ttitude hypothesis*- A person with a more positive environmental attitude will lead to better eco-friendly product recommendation and rating, a greater number of product uses, and a greater chance of continued use.
2. *User activity hypothesis*- A product with difficult set-up or cleaning will lead to a worse eco-friendly product recommendation and rating, a fewer number of product uses, and a smaller chance of continued use.

The attitude hypothesis states that environmental attitude affects eco-friendly product acceptance. If a person has a negative attitude toward the environment and feels that there is no need to behave in environmentally friendly ways, then they will probably be less likely to accept more eco-friendly product alternatives. The environmental attitude variable will be measured with the NEP scale described previously. The user activity hypothesis states that the user activities associated with a product will affect product acceptance. A previous study was completed with eco-friendly versions of mp3 speakers and showed that user activities may indeed affect the user's opinion of the product (Esposito and Linsey 2012).

Survey questions will be used to measure three main user activity variables: difficulty of initial product set-up, difficulty to clean the product, and length of time required to operate the product on a daily basis. The dependent variable of "product acceptance" will be measured using a survey that asks several questions regarding the success of the product. The exact questions will be detailed further in the following sections. These hypotheses will be tested using a between-participants study where participants take home one eco-friendly product to test for a week and then return to complete surveys asking about their experience with the product.

The third pilot experiment tests the design method of the default option. Six automatic paper towel dispensers are used in the experiment. The dispensers are set to various lengths of paper towels for a one week period and the corresponding paper towel usage is measured. Over a three-week testing period, the dispensers are inspected and the usage is measured. It is believed that the users will choose the default option if the length of towel is an average length, but when the towels are set too short, the user will not choose the default option and will take multiple sheets of towels.

The following chapters will describe each of the three pilot experiments in detail. The experimental method will be presented first, which specifies the product selection process as well as the details of the questionnaires given to the participants. Then, the results will be presented with discussion and finally the conclusions of the experiment.

CHAPTER II

INITIAL PILOT EXPERIMENT

Introduction

To begin the experimental design for this research, several questions have been raised concerning eco-friendly design, and are presented in the following section. Products which are alternatives to disposable plastic water bottles have been purchased and tested with a between-participants study to determine the accuracy of the posed hypotheses. The main concern of this experiment is to determine the variables that relate to eco-friendly product acceptance. The idea of testing alternative products to disposable plastic water bottles has been chosen because there are several different types of alternative products on the market, they are inexpensive, and they are easy to give to participants to test. Several alternative products to plastic water bottles have been researched and a few have been selected. The method of selecting the appropriate products to test is done by analyzing each product's activity diagram as well as Table 1, which compares each of the product's features. Once the products have been selected for the experiment, a product evaluation survey is created for the participants to fill out regarding the product they tested. The initial pilot experiment for this research helps to determine the whether the experimental procedure, product surveys, and the products themselves are adequate to answer the posed research questions. The research questions are detailed further in the following section.

Hypotheses

The basis of the initial pilot experiment is exploratory in nature and several questions were raised before the experiment took place. The product evaluation survey asks the participants about the product they tested, and their responses will help to evaluate these research questions.

1. Will the participants be less motivated to use the eco-friendly products if they require more user activities?

2. Does a positive attitude toward the environment mean the participant is more likely to change their behavior?

3. Does the product help the user to replace their previous poor environmental habits with new, more eco-friendly habits?

4. Which features are successful and which are unsuccessful?

Based on the research questions, there were two hypotheses formulated- the attitude hypothesis, and the user activity hypothesis.

Attitude hypothesis- A person with a more positive environmental attitude that uses an eco-friendly product will lead to better eco-friendly product recommendation and rating, a greater number of product uses, and a greater chance of continued use.

User activity hypothesis- A product with difficult set-up or cleaning will lead to a worse eco-friendly product recommendation and rating, a fewer number of product uses, and a smaller chance of continued use.

Products

This research includes testing of four different products: the Brita filtration water bottle, the 321 water bottle, the Botl filter, and the Filtrete water station. The products have been chosen by first researching many alternatives to disposable plastic water bottles, and the complete list of products found is shown in Table 1. An activity diagram for each of the eight products found has been created as well as one for a typical disposable water bottle (found in appendix A). The user activities related to a product are believed to affect whether a person will continue to use the product. If a product requires difficult user activities, it may deter the person from using the product. All of the products have been closely examined and a list of positive product features has been created, which is shown in Table 1. The list of product features includes eight characteristics: easy set-up, easy maintenance, short time to operate, refillable, long filter life, indicates filter change, low cost, and all-inclusive. Descriptions of the features are described below:

Easy Set-up- The product should be easy and fast to set up before use.

Easy Maintenance- The product should be easy to clean and not require frequent filter changes.

Short Time to Operate- The time to filter water should be fast and there should not be many processes to operate the product on a daily basis.

Refillable- The product should be able to be refilled throughout the day so that the user can have clean filtered water all day.

Long Filter life- If the product has a filter, it should have a long filter life so they do not have to replace it frequently.

Indicates Filter Change – The product should alert the user when the filter needs to be changed.

Low Cost- The cost of the product should be low. The replacement filter cost may also need to be considered.

All-Inclusive- The products should be all inclusive so that they do not require additional products to function.

The products have been examined and evaluated based on each feature. The table comparing each product as well as a plastic disposable water bottle is shown in Table 1 with the selected products highlighted. Each product is unique with a different set of product features and the only product that has all the features is the Brita water bottle.

Table 1. Product feature comparison.

	FEATURES							
PRODUCTS	Easy set-up	Easy Maintenance	Short Operation Time	Can Refill Bottle throughout day	Long Filter Life	Indicates Filter Change	Low Cost	All-Inclusive
Filtrete Water Station					x	x		x
Botl Filter	x		x	x			x	
Brita Water Bottle	x	x	x	x	x	x*	x	x
Metal Water Bottle	x	x	x		n/a	n/a	x	
Filter Straw	x	x	x	x	x		x	
321 Water Bottle				x	x			x
Faucet Filter		x	x		x	x		
Filter Water Pitcher	x	x			x	x	x	
Disposable Bottle	x	x	x		n/a	n/a	x	x

* indicates that the person can sign up for filter change warnings online

The process of selecting the products for the study includes examination of all the product activity diagrams and the table of product features. The four products have been selected because their activity diagrams and features differ largely from each other and from the disposable water bottle so the participants can test a wide variety of product features and activities. Each product used in the first pilot experiment is described below.

321 water bottle

The first product presented in Figure 2 is the 321 water bottle. This product is set-up by inserting the filter at the end of the blue plastic piece in the center of the bottle. The filtration system mimics a French press and works by filling the bottle with water and then pushing the plunger slowly through the entire length of the bottle. Once this has been done, the water is ready to drink. When the bottle is empty, the user must remove the plunger and repeat the filtration process. Because the 321 water bottle has an internal plunger system, the cleaning and maintenance may seem complex and lengthy to the user. In addition, the time it takes to filter the water is long because the plunger must be pushed slowly to avoid breaking the thin plastic rod.

Figure 2. 321 water bottle.

The Botl filter

The second product presented in Figure 3 is the Botl filter. This product consists of a small metal tube with holes and two plastic end caps that are removable. As shown in the image, this product comes with small filtration bags, which are inserted into the metal tube. Once the user inserts the bag and closes the tube with both end caps, the Botl filter is simply placed in a water bottle of their choice. The bottle is then filled with water and shaken several times. A disadvantage to this product is that it is not all-inclusive since an additional product (a water bottle) must be used in conjunction with the Botl filter. In addition, a single filtration bag should be replaced every three days, which is a very short filter life and means the user must purchase filter bags regularly to continue using the product. Benefits to this product are easy set-up and short operation time.

Figure 3. Botl filter.

Filtrete water station

The next product shown in Figure 4 is the Filtrete water station. This product consists of a stand that holds four water bottles and a basin on top that holds a water filter. Once the product is assembled, the user must place the water station under a faucet and fill the basin until the water bottles are full. A disadvantage to this product is that once the user takes a bottle with them, say to work or school, they cannot refill the bottle with filtered water if they are away from the water station system. The product also takes a long time to filter enough water through to fill up all the water bottles.

Figure 4. Filtrete water station.

Brita filtration water bottle

The final product used in this experiment is the Brita filtration water bottle and is shown in Figure 5. This product is simple to operate and takes a relatively short time to use on a daily basis. After the product is initially set-up, the user just needs to fill the bottle with tap water and screw on the cap. To drink, the user must squeeze the bottle to push the water through the filter and out the nozzle. The Brita water bottle is the only product that has all the product features described earlier, though the bottle itself does not remind the user to change the filter but they can sign up for reminders online.

Figure 5. Brita water bottle.

Activity diagrams

In this section, the activity diagram for each product used in the study is presented (all activity diagrams are located in appendix A). These diagrams have been initially developed to determine which products were suitable for the experiment. Then, each diagram has been studied so that a few characteristics could be determined. Three main features have been examined- the activities required for initial set-up, the complexity of activities, and the overall complexity of the diagram. The first activity diagram shown in Figure 6 is for disposable plastic water bottles. The overall length of the diagram is very short and requires almost no set-up activities. The activities are simple and do not require a lot of effort or time.

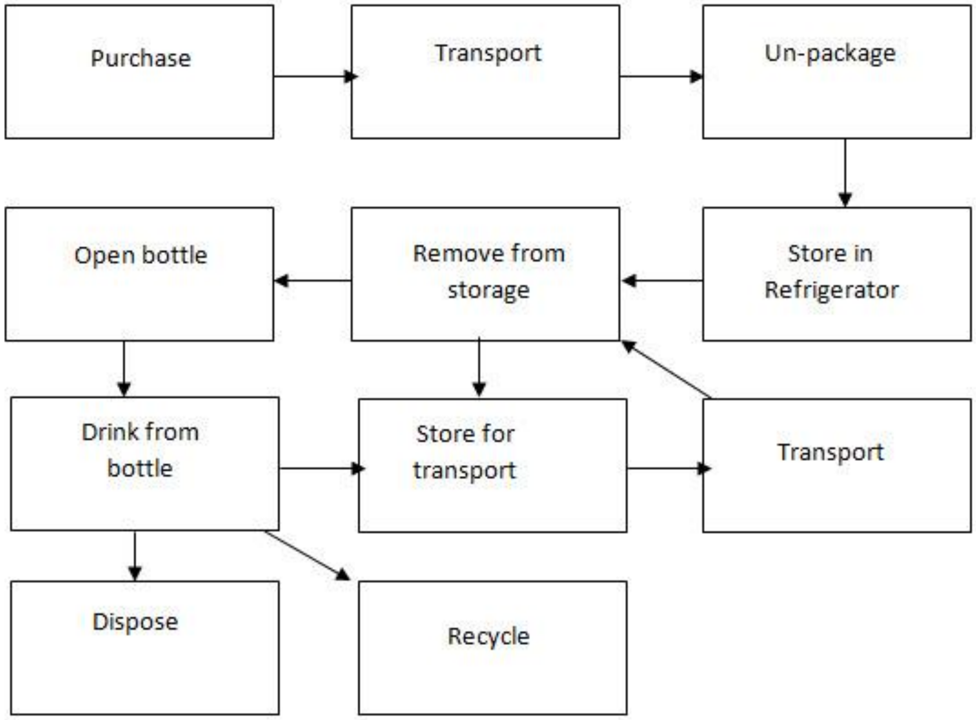

Figure 6. Activity diagram for disposable plastic water bottles.

The next activity diagram presented is for the Filtrete water station shown in Figure 7. It is apparent that the overall length of the diagram is much larger than the disposable plastic water bottle diagram. There are many more user activities and a lengthy set-up process for this product. The time required to operate the Filtrete water station is much longer than a typical disposable water bottle and it involves more maintenance and cleaning. A negative aspect of this product is that once the user fills the water bottle and takes it with them; they cannot refill it again with filtered water while away from the water station.

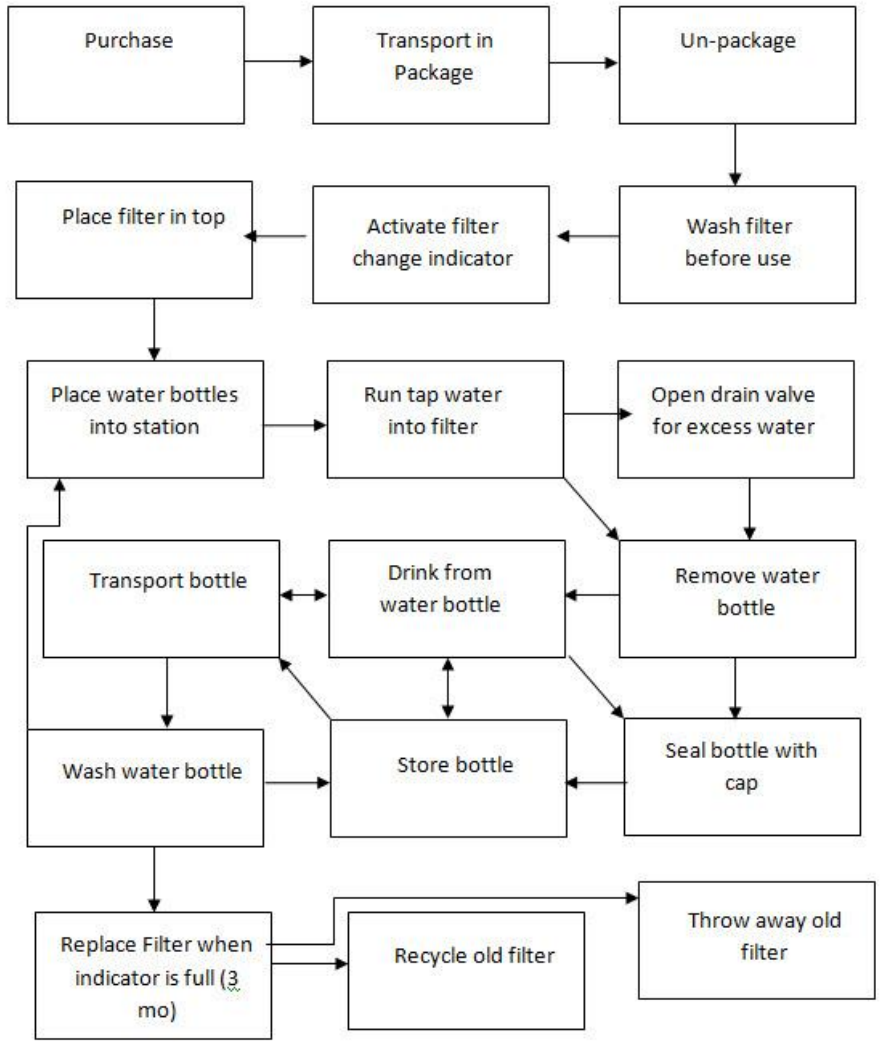

Figure 7. Activity diagram for the Filtrete Water Station.

The next activity diagram shown in Figure 8 is for the Botl filter product. This diagram is quite different because the Botl filter must work in conjunction with a water bottle (non-disposable). The activities involving only the Botl filter are coded in red, water bottle activities in blue, and activities involving both the Botl filter and water bottle are in purple. The overall size of the diagram is also larger than the disposable water bottle, thus it requires more user activities. The initial set-up requires many steps, but they are easy and not very time consuming. A positive aspect to this product is that the user can refill the water bottle throughout the day if needed. A negative feature is that the user must replace the filter bags every three days, which is quite often compared to all the other products thus maintaining the product is more difficult.

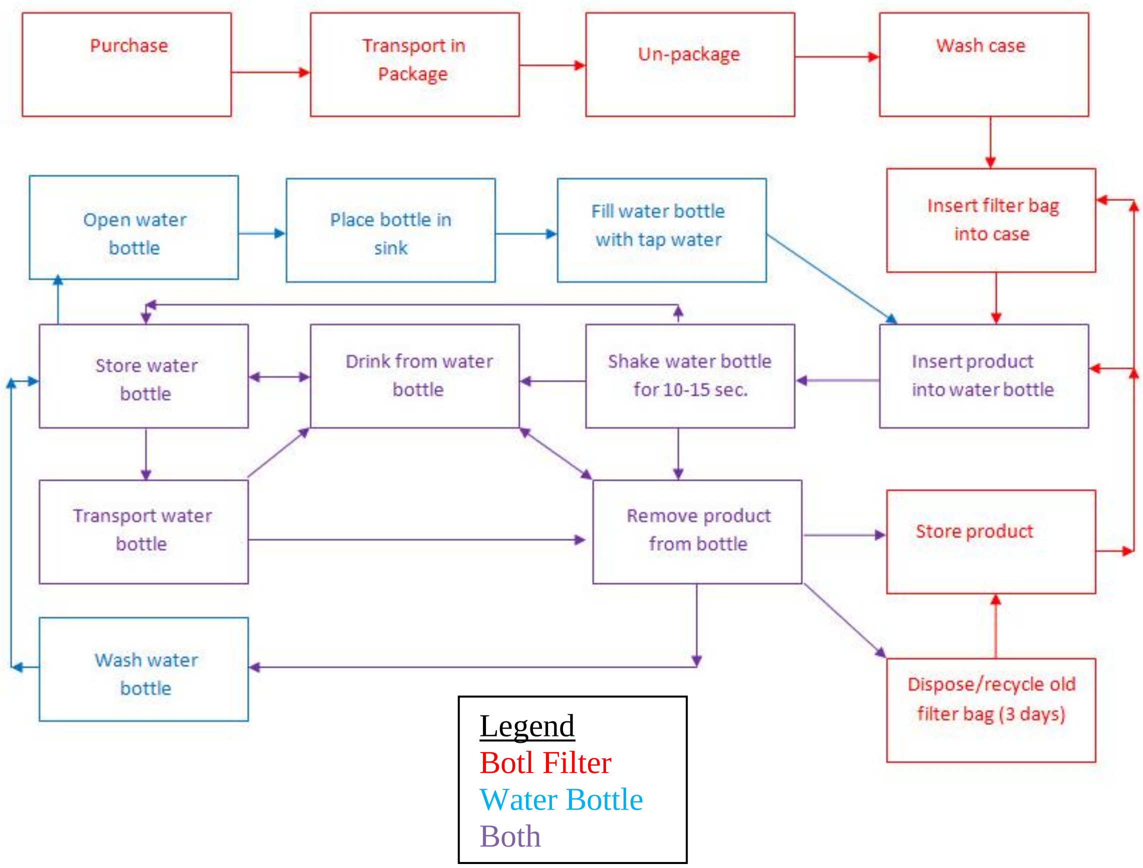

Figure 8. Activity diagram for the Botl filter.

The next activity diagram shown in Figure 9 is for the Brita filter water bottle. The overall size of the diagram is small and requires about the same number of activities as the disposable water bottle. The initial set-up is slightly more complex than the disposable bottle, but otherwise the activities are similar. An advantage that the Brita bottle has compared to the disposable bottle is that it can be refilled throughout the day so the user can have clean filtered water all day long. The actual product does not indicate filter changes like the Filtrete water station does, but the user has the option to sign up for filter change reminders online.

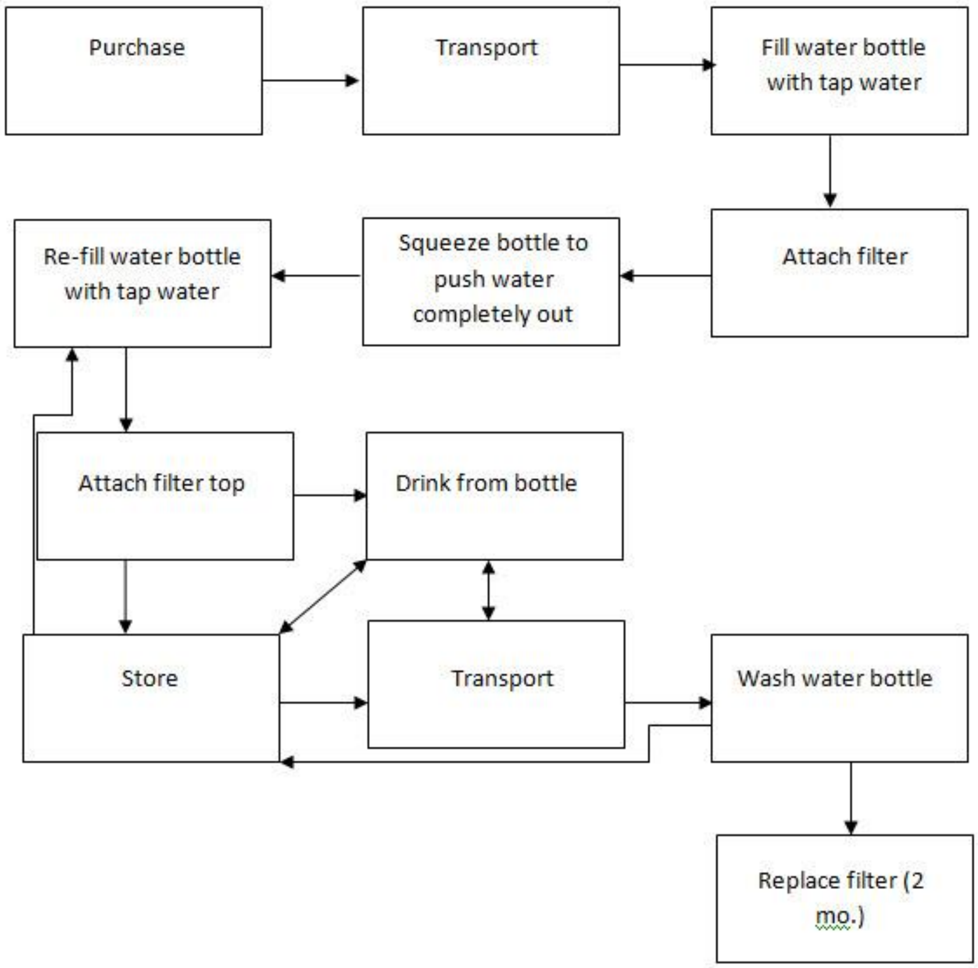

Figure 9. Activity diagram for the Brita water bottle.

The final activity diagram presented is for the 321 water bottle depicted in Figure 10. The overall complexity of the diagram is about in the middle for the products we are testing. The initial set-up for this water bottle is complex and involves many steps. For this product, the order of activities is important because the user must completely empty the bottle before removing the plunger, or the bottle could be damaged in some way. On a daily basis, this product is simple to use, but the main disadvantage is that the time of operation is long. The user cannot simply fill the bottle and screw on the cap as with the Brita water bottle. When refilling the bottle, the user must empty any remaining water, remove the plunger, fill bottle with water, and then slowly push the plunger back in the bottle. Another downfall for this product is that it does not alert the user when the filter needs to be changed, nor offers online filter change warnings.

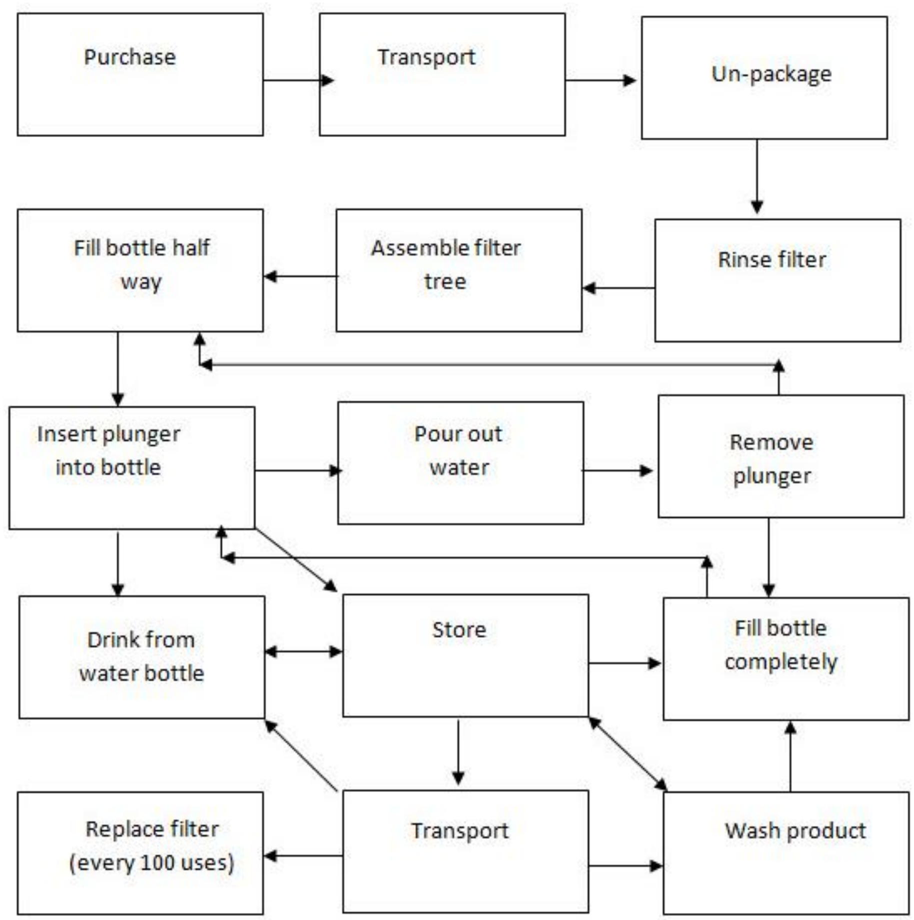

Figure 10. Activity diagram for the 321 water bottle.

Experimental procedure

Participants for the initial pilot experiment are mechanical engineering students recruited from their senior design class. Each participant is randomly assigned one product of the four possible products to use for a one-week testing period. They are addressed individually in an experiment room when they receive the product and information about the study. The participants are told that they are being asked to take home a product to use for an engineering design study. They are told that the product instructions are in the box with the product, if they would like to read them before use. The complete experiment script is given in appendix B. After a week of using the product, the participants return and complete two questionnaires. The first survey they complete is the product evaluation survey and the second survey is the demographics questionnaire. The product evaluation form measures the success of the product and asks what features they like or dislike. The demographics survey measures environmental consciousness and a few demographic variables. As compensation, the students keep the product they test and receive class credit in their design class.

Questionnaires

There are two different surveys, the demographics survey and the product evaluation survey, that participants have been asked to complete after testing the eco-friendly products. The demographics survey asks basic questions such as age, gender, education, and political views (appendix C). Environmental consciousness is assessed on the survey through several questions about environmental attitude and behavior. Environmental attitude is the first part of the survey, and is determined using the 15 Likert item NEP scale developed by Dunlap *et al.* (2000). The participants are given a series of statements about the environment and are asked if they strongly agree, mildly agree, are unsure, mildly disagree, or strongly disagree. Environmental behavior is the second part on the survey, and is calculated using the 30 true/false items in the EAS scale devised by Maloney, Ward, and Braucht (1975). Part three of the survey is a single question used to evaluate self-designated environmental consciousness. The question is stated, “All things considered, would you classify yourself as an environmentalist?” In part four, questions are asked to measure the participants’ willingness to make life-style changes because of environmental problems. There are nine life-style changes given and the participant is asked if they did this, were willing to do this, reluctant to do this, or even opposed to do this. The questions from part three and four were replicated from the research of Krause (1993).

The product evaluation survey asks the participants about their weeklong experience with the product (appendix D). The first few questions ask whether they would recommend the product to a friend or family member, whether they would continue to use the product, what they would rate the product on a 1-7 scale, and how often they used the product. The answers to these questions will help to determine whether the product was successful or unsuccessful. The participants are also asked whether they typically used plastic disposable bottles and if they thought the product they tested would change their habit. A few specific questions are asked to determine whether the set-up and maintenance of the product were difficult. The end of the questionnaire included a few short answer questions. They are asked to describe what they liked most and least about the product and to explain why. Another important question asks whether the product influenced them to become more eco-friendly in other aspects of their life.

Participants

For the first pilot experiment, there were 11 mechanical engineering students recruited from their senior design class at Texas A&M University. As compensation for their participation, they were given extra credit in their design class and were allowed to keep the product they tested. There were nine males and two females and all participants were between 20-33 years of age. Of the eleven participants that volunteered to participate in the study, four of them were assigned the Filtrete water station, four used the Brita water bottle, one used the Botl filter, and two used the 321 water bottle. A complete, detailed data table for the initial pilot experiment is in appendix F.

Results

There are two hypotheses being tested in the first pilot experiment. The first is the attitude hypothesis, which states that a person with a more positive environmental attitude will lead to better eco-friendly product recommendation and rating, a greater number of product uses, and a greater chance of continued use. The second hypothesis is the user activity hypothesis, which states that a product with difficult set-up or cleaning will lead to a worse eco-friendly product recommendation and rating, a fewer number of product uses, and a smaller chance of continued use. The two variables associated with the product user activities are difficulty of product set-up and difficulty of product cleaning/maintenance. Therefore, the three independent variables measured in the experiment are environmental attitude, difficulty of set-up, and difficulty of maintenance. There are five dependent variables: recommendation of product, continue to use product, product rating, total success of product, and number of uses.

In addition to testing the hypotheses, the purpose of the first pilot experiment is to test the experimental design to ensure that the surveys are adequate for measuring all the desired variables. Another important aspect of the first pilot experiment is to make sure the products chosen to test the hypotheses are sufficient and do not introduce any extraneous variables to the experiment.

Lessons learned

Many issues in the experimental design became known after analyzing the data from the initial pilot experiment. The most important realization is that there were many variables unaccounted for in the experimental design, and this became apparent in the product evaluation survey. The participants were asked to record what they liked most and least about the product on the open-ended part of the survey. The list of the positive and negative features is shown in Table 2.

Table 2. Positive and negative features of products.

Positive product features	**Negative product features**
Portable	Lid design
Aesthetics	Aesthetics
Multiple bottles	Bottle design
Quick to use	Poor filtration
Easy installation	Difficult installation
Size	Size

There were many features on this list that were not measured in the experiment, therefore they are not being controlled for. Factors such as aesthetics, bottle design, and lid design are examples of these extraneous variables and are likely affecting the participants' opinion of the product greatly. This is an unanticipated result of the experiment, and a simple solution can be implemented so that many of the variables are controlled. The solution is to change the products that are tested and keep the water bottle consistent in all conditions of the experiment. This way, the aesthetics, bottle design, lid design, and size are now controlled. For the next pilot experiment, the same water bottle will be given to the participants for all the conditions, and the method of filtration will vary in each condition. The water station and 321 water bottle will be removed from the experiment and replaced with the Brita faucet filter and the Brita filter pitcher.

In addition to changing the products, it was decided that all the participants recruited for the experiment should typically use disposable bottles as a main source of their drinking water. In the first pilot, only three of the eleven participants reported that they typically use disposable plastic water bottles. An important part of this study is to determine whether the new product changes their habit of using disposable bottles, so in order to measure this, all of the participants must typically use disposable bottles.

In addition, an independent variable, operation time, will be added to the product evaluation survey. This will be done because the time to operate each product on a daily basis is different for each product and may affect whether the user will accept the new product in exchange for disposable plastic water bottles.

Attitude hypothesis results

For the attitude hypothesis, it is assumed that a positive environmental attitude will lead to pro-environmental behaviors. In this experiment, the participants with a higher attitude score from the NEP scale should be more willing to accept eco-friendly products. A multinomial logistic regression using SPSS software determines whether attitude is related to any of the dependent variables: recommendation, continue to use, rating, and number of uses. A logistic regression is performed because it is a more appropriate regression analysis for categorical dependent variables and continuous independent variables. For the analysis in SPSS, a logistic regression is done with one dependent variable and the independent variable of environmental attitude. This process is completed for each of the dependent variables. The results for the regression analysis are summarized in Table 3.

Table 3. Regression analysis for attitude.

Dependent Variable	Chi-Square	p-value
Recommendation	16.34	0.75
Continue to use	11.65	0.11
Rating	17.25	0.24
Number of uses	20.16	0.51

The alpha value used in this experiment is $\alpha = 0.1$, and based on the results of the regression analysis, there is no significance between the participants' level of environmental attitude and any of the dependent variables. The results show that attitude does not affect the participants' opinion of the product, though with a larger sample size, it is possible that the "continue to use" variable will be significant. As mentioned previously, additional, uncontrolled variables may have affected the participants' opinion of the product, thus affecting recommendation, number of uses, etc. These issues may have altered the data, and if controlled, the regression analysis for attitude may be different.

User activity hypothesis results

For the activity hypothesis, it is assumed that difficulty of product set-up and difficulty of product cleaning/maintenance will affect the participants' overall opinion of the product and whether they will accept it. The same regression analysis has been done with the other two independent variables: set-up difficulty and cleaning/maintenance difficulty. Of the eleven participants, only two reported that their product was difficult to set-up and two reported that it was difficult to clean/maintain. The two products that were reported as having difficult set-up and difficult maintenance were the Filtrete water station and the 321 water bottle, which was predicted in the list of product features shown in Table 1. The result for the regression analysis for set-up difficulty is shown in Table 4 and maintenance difficulty in Table 5.

Table 4. Regression analysis for set-up difficulty.

Dependent Variable	Coefficient	Standard error	p-value
Recommendation	-0.44	0.65	0.51
Continue to use	-0.44	0.39	0.28
Rating	-1.44	0.39	0.00
Total Success	-2.33	0.90	0.03
Number of uses	-3.17	1.49	0.06

Table 5. Regression analysis for maintenance difficulty.

Dependent Variable	Coefficient	Standard error	p-value
Recommendation	0.17	0.66	0.81
Continue to use	-0.44	0.39	0.28
Rating	-0.22	0.61	0.73
Total Success	-0.50	1.18	0.68
Number of uses	0.19	1.82	0.92

There is significance between set-up difficulty with rating, set-up difficulty with total success, and set-up difficulty with number of uses. Based on the regression results, there may be a relation between difficulty of product set-up and the participants' overall opinion of the product, as well as how often they use the product. Based on the results for maintenance difficulty, the difficulty of cleaning or maintaining the product has little or no effect on the participants' opinion of the product.

In addition to performing a regression analysis, several graphs that compare each product will help to determine whether there is a particular product that performed well or a product that performed poorly. Figure 11 shows the average recommendation for each product.

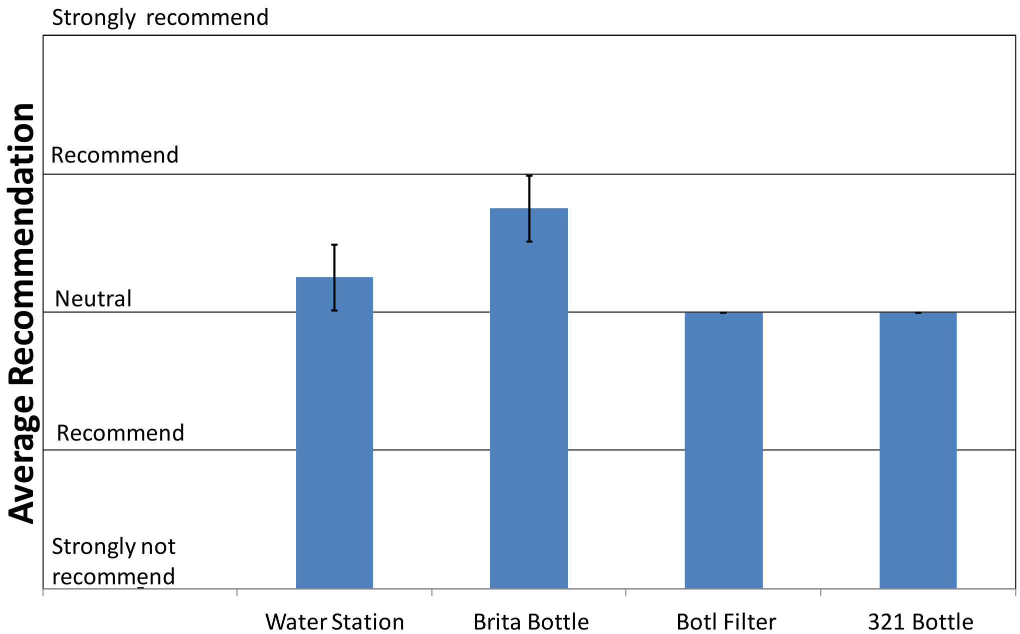

Figure 11. Average recommendation with error bars +/- 1 standard error.

The Brita water bottle performed the best based on the question whether or not they would recommend the product to a friend or family member. The other three products all have about the same neutral recommendation.

The participants were asked to rate the product on a 1-7 scale where one was the best product they had ever used and seven was the worst. The results for this question are shown in Figure 12.

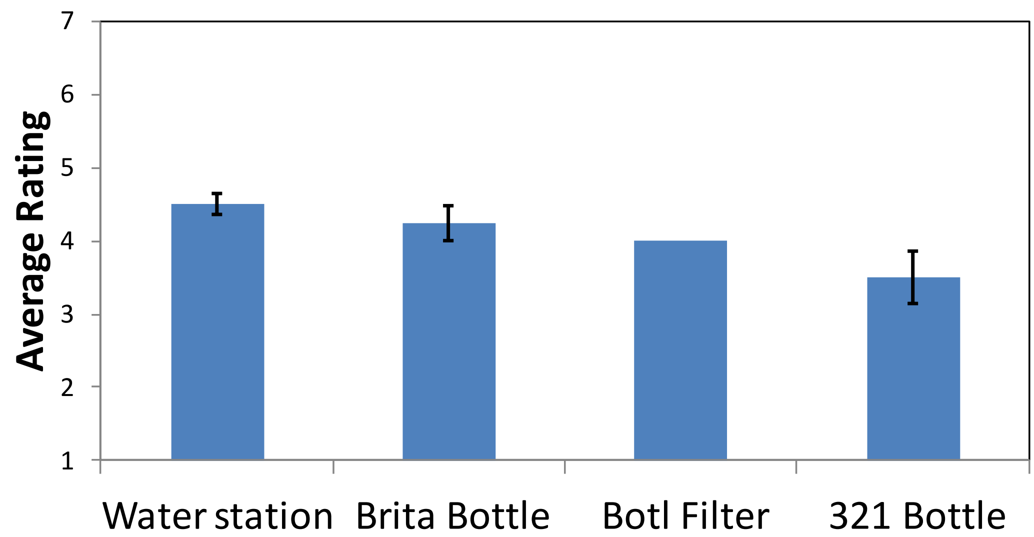

Figure 12. Average rating for each product with error bars +/- 1 standard error.

As for the product rating, all the products have a similar score of about four on the 1-7 scale. The result for the total success of each product is shown in Figure 13.

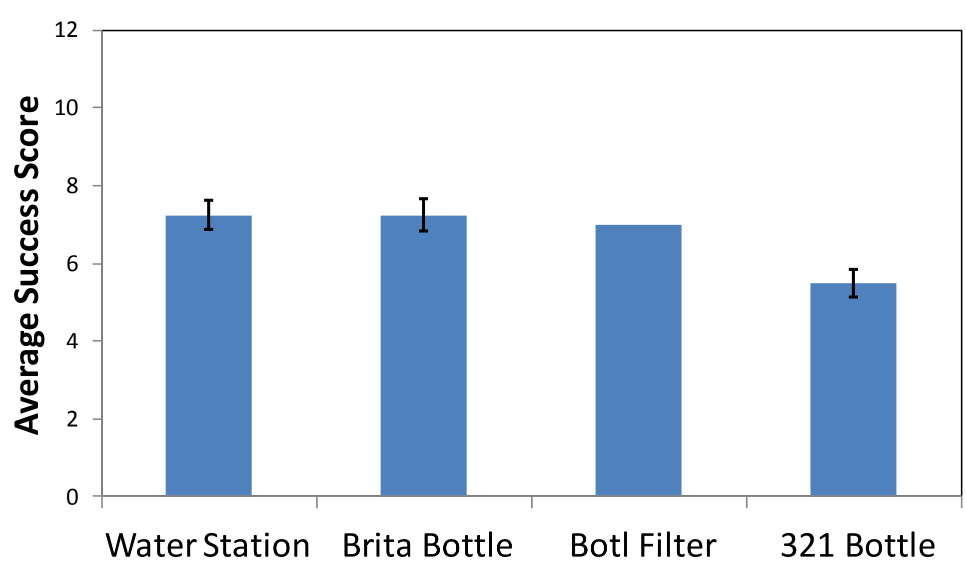

Figure 13. Average total success score with error bars +/- 1 standard error.

Similar to the product ratings, the average total success scores are about the same for all the products. This metric includes the scores from the product recommendation, continue to use the product, and the product rating questions.

The participants were also asked to report how often they used the product in the week they tested it. Their options were 1-2 days, 3-4 days, 5-6 days, and daily. The result for the average number of uses for each product is given in Figure 14.

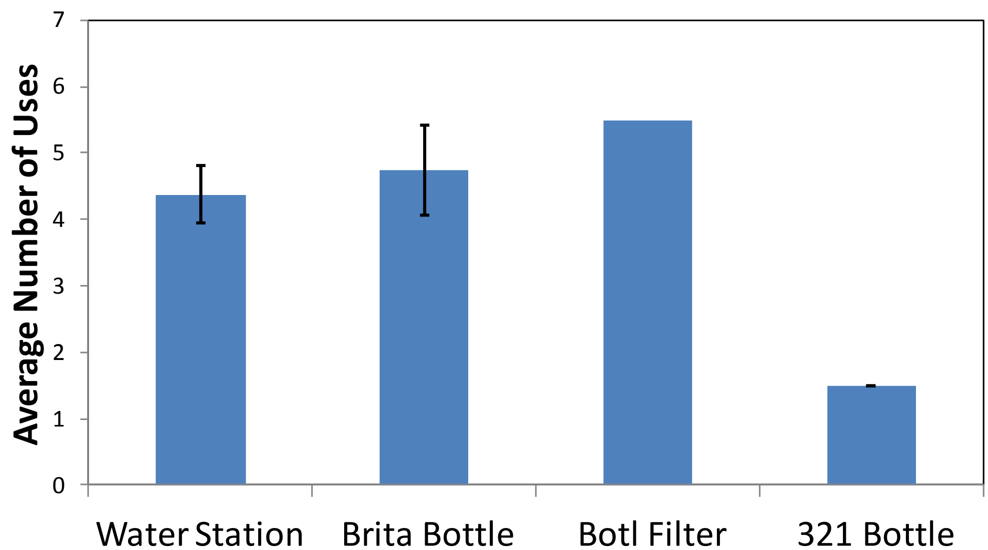

Figure 14. Average number of uses (in days) with error bars +/- 1 standard error.

It seems from the results that the 321 water bottle was not used as much as the other three products. This may be because the participants find it difficult to set-up and use on a daily basis. The Botl filter has the highest number of uses, but there is only one data point for this product so this may not be the case for a greater sample size.

Based on the results, the 321 water bottle scores consistently poor on many of the comparisons. One of the students reported that it was both difficult to set-up and difficult to clean/maintain. The other participant that tested the product reported that they do use disposable plastic water bottles, but this product would not change this habit. The Brita water bottle scores consistently well in all categories and is the only product to score a "strongly recommend" for the product recommendation question. This product was expected to do well because it possesses the entire list of positive product features described in Table 1.

CHAPTER III

CONSISTENT BOTTLE EXPERIMENT

Introduction

For the second pilot, many aspects of the experiment have been changed due to the findings from the first pilot experiment. Most of the products are different because it has been realized that there are too many undesirable variables present in the initial experimental design. When designing the first pilot experiment, it was believed that the product features should all be very different from each other so the participants could test a wide variety of features and user activities. This lead to extraneous variables such as aesthetics, durability, and bottle lid design that were reported by the participants in their product evaluation surveys. Since these variables are not being controlled for in the experiment, a better more controlled experimental design is needed. The best solution for this problem is to choose a single water bottle that would be used by all participants. This way, the water bottle remains the same and the water filtration method varies across each condition.

In addition to the product change, all participants recruited for the experiment should typically use disposable water bottles. For the second pilot experiment, only participants that regularly use disposable water bottles have been recruited to participate. It is important for this study to determine whether the alternative products actually change the participants' habits of using disposable water bottles. Since most of the participants in the first pilot experiment reported that they do not typically use disposable bottles, we were not able to measure whether the product actually changed their habits. The questionnaires have been changed significantly to reflect the problems in the first pilot. The changes are detailed in the following sections.

Products

The products tested in the second pilot experiment include three new products- the Brita faucet filtration system, the Brita filter water pitcher, and the Clear2Go filter water bottle. The Botl filter has been continued from the first pilot. There are four conditions in the consistent bottle experiment:

1. Clear2Go water bottle with Clear2Go filter

2. Clear2Go water bottle with Brita faucet filter

3. Clear2Go water bottle with Brita filter pitcher

4. Clear2Go water bottle with Botl filter

Therefore, the water bottle is consistent with all conditions and the difference is the filtration method of the filter water bottle- the faucet filter, the Botl filter, or the water pitcher.

Each of the products has been compared and a new table of product features has been created. Many of the variables are now controlled for and only three features are compared: Easy set-up, Easy cleaning, and Short operation time. The new table is shown in Table 6.

Table 6. Comparison of product features for second pilot experiment.

	FEATURES		
PRODUCTS	Easy set-up	Easy Cleaning	Short Operation Time
Botl Filter	**x**		**x**
Filter Water Bottle	**x**	**x**	**x**
Faucet Filter		**x**	**x**
Filter Water Pitcher	**x**	**x**	

The Brita faucet filter is shown in Figure 15 along with the Clear2Go water bottle (with filter removed). The initial set-up of this product may prove to be difficult for the user because it involves many steps. Once the product is set up however, it is very simple and fast to use on a daily basis. The cleaning and maintenance is also very easy for the user.

Figure 15. Brita faucet filter and water bottle.

The product shown in Figure 16 is the Clear2Go filter water bottle. This is the water bottle that will be used for all four conditions but for the faucet filter condition, Botl filter condition, and the water pitcher condition, the filter will be removed. This product was chosen to replace the Brita filter water bottle because there was a need to provide the participants with a product they would not recognize so they would not realize the filter was removed. This product has the same exact features and activity diagram as the Brita water bottle. It has a short operation time, is very easy to set up, and is easy to clean because it can be washed in the dishwasher as long as the filter is removed prior to washing.

Figure 16. Clear2Go filter water bottle.

The product shown in Figure 17 is the Brita filter pitcher and the Clear2Go water bottle with filter removed. This product has a relatively simple set up process for the user and is easy to clean and maintain. The downside to this product is that the operation time is long. In order for the user to fill the pitcher completely with filtered water, they must full up the basin and wait for the water to slowly filter through. Then, they must add more water and wait for it to filter through again. It may take two or three times to fill up the pitcher with water. This is a long time for the user to wait and may act as a barrier to accepting the product as an alternative to disposable plastic bottles.

Figure 17. Brita filter pitcher and water bottle.

The final product used in the second pilot experiment is the Botl filter with Clear2Go water bottle. This product was also used in the first pilot experiment and has been continued in the second because no major extraneous variables were found to be associated with this product. The difference is that a water bottle will also be given to the participants in addition to the Botl filter.

Figure 18. Botl filter with water bottle.

Activity diagrams

The activity diagrams for the two new products have been created so that certain product features could be identified. The activity diagram for the Botl filter and the filter water bottle are presented in the previous section and are shown in Figure 8 and Figure 9 respectively. The activity diagram for the Brita faucet filter is shown in Figure 19.

It is obvious from the diagram that the initial set-up process for the faucet filter is very lengthy and requires a few tasks that may be difficult for the user. Once the product is installed however, the activities required to use on a daily basis are actually very simple and not time consuming at all.

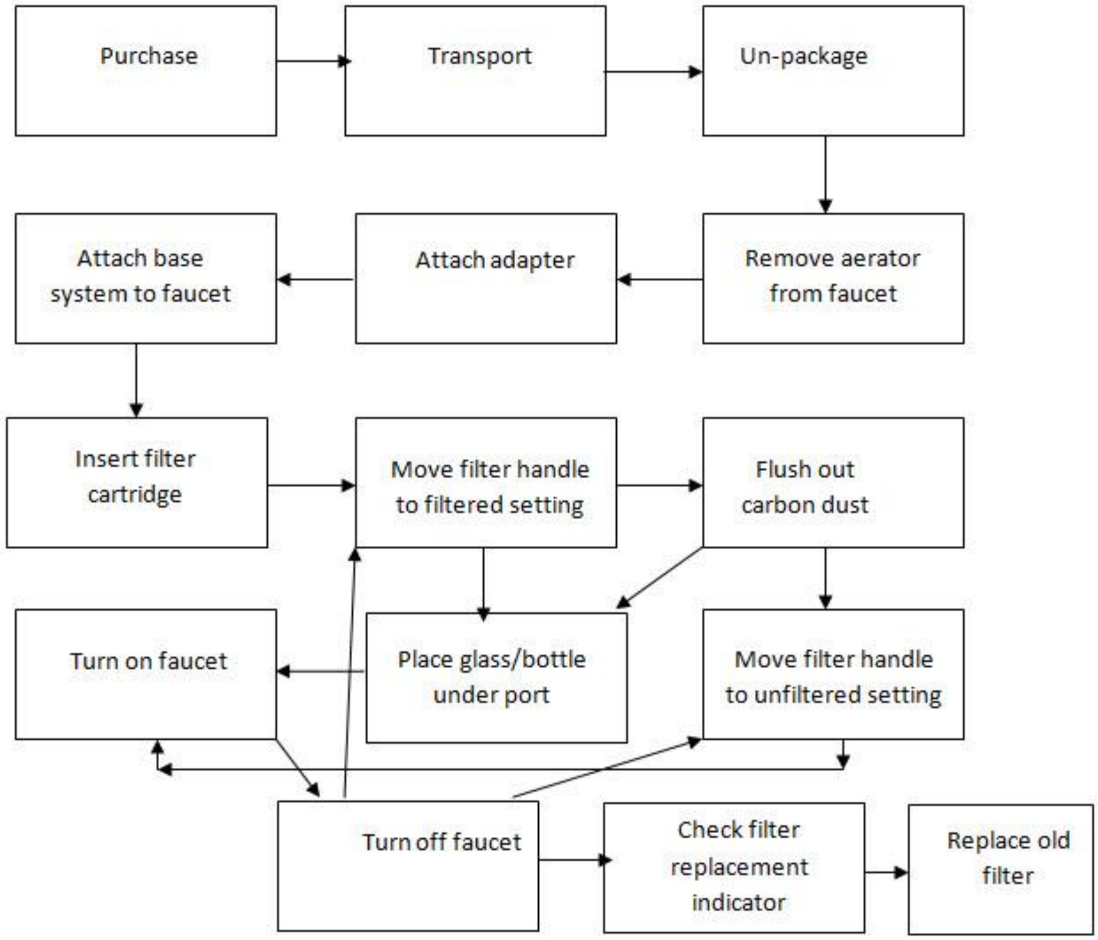

Figure 19. Activity diagram for the Brita faucet filtration system.

The activity diagram for the Brita filtration pitcher is shown in Figure 20. The set-up for the pitcher is simple and does not require many user activities. The overall complexity of the diagram is relatively simple and there are no activities that are particularly difficult for the user. The negative aspect for this product is that some of the activities require a lot of time spent by the user. The main activity that requires the most time is filling the pitcher with tap water. The user must fill up the basin and wait for the water to filter through. Usually, this is a very slow process and the user may often have to do this multiple times to fill the pitcher completely.

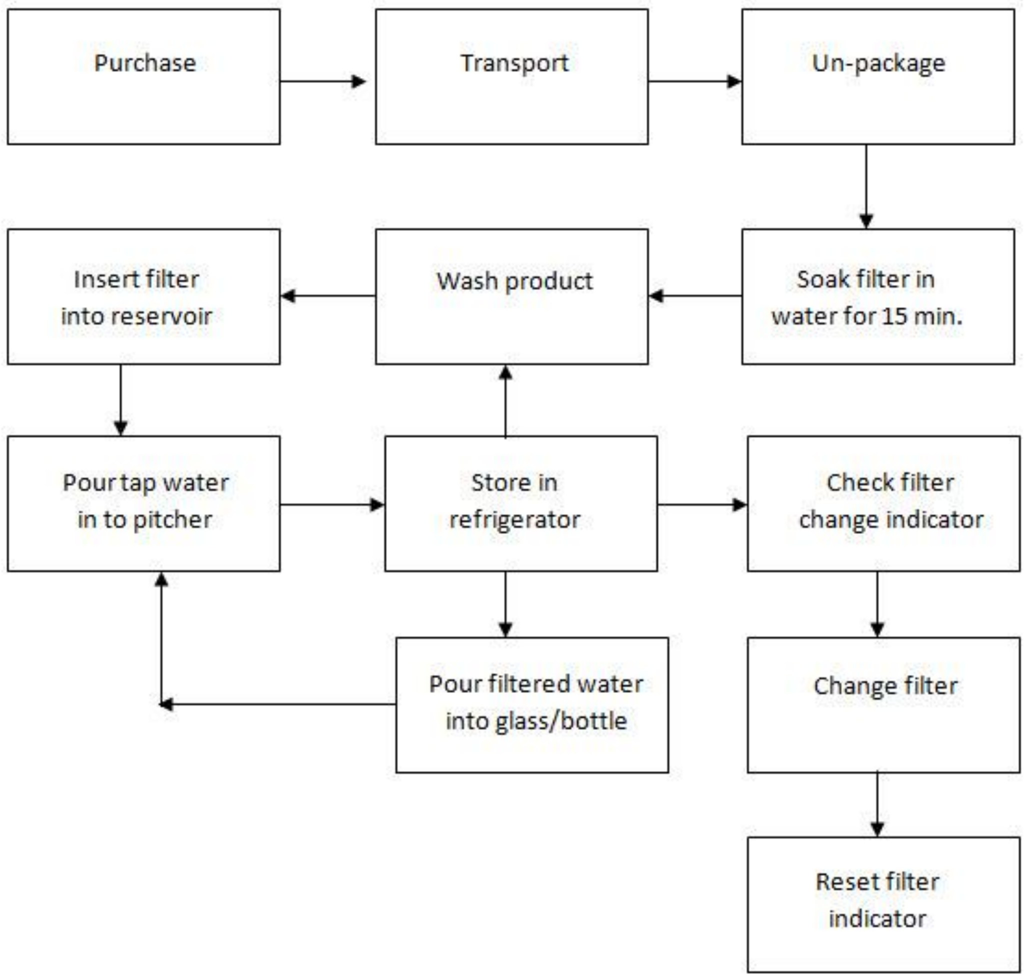

Figure 20. Activity diagram for the Brita filtration pitcher.

Questionnaires

The product evaluation survey used in the second pilot has been changed considerably from the initial survey used. A new section has been added to determine the participants' habits concerning their use of disposable plastic water bottles. The survey asks how many bottles the participant uses on a weekly basis and the brand(s) they buy. It also asks whether they refill their disposable bottles and if they use non-disposable bottles in addition to disposable ones. The next section is similar to the initial pilot survey, in that it asks several questions about the product, like whether they would recommend it, whether they will continue to use it, and how often they used the product in the past week. The survey also asks whether the product was difficult to set-up and clean and how much time it took them to do so. To measure the added variable of operation time, a question has been added asking whether the product required too much time to operate on a daily basis. An additional free response question has been added at the end of the survey that states, “In what ways would you change the product so that you would use it more?” Knowing what the participants’ would change about the product will help to identify undesirable product features and possible solutions to fix them. The survey used in the second pilot experiment is shown in appendix E.

In addition to the two surveys, a single interview question has been asked at the very end of the experiment. The participants will be asked, “What was your overall opinion about the product that you tested? Did you like it or not and why?” The purpose of this interview question is to determine the participants’ view on the product they tested and whether they had any sort of bias toward the product to begin with. Any additional uncontrolled variables may become obvious with this interview question. The following section will present the results and discussions of the experiments described thus far.

Participants

Posted flyers were used to recruit students of all majors on the Texas A&M University campus. The flyers specified that the participants must typically use disposable plastic water bottles as a source for their water. Eight participants were recruited for the consistent bottle experiment, two per condition. The participants included five women and three men, all between the ages of 18-24. The complete data tables for the consistent bottle experiment is given in appendix G.

Results

The same two hypotheses are tested in the second pilot experiment- the user activity hypothesis and the attitude hypothesis.

Attitude hypothesis- A person with a more positive environmental attitude that uses an eco-friendly product will lead to better eco-friendly product recommendation and rating, a greater number of product uses, and a greater chance of continued use.

User activity hypothesis- A product with difficult set-up or cleaning, or a long operation time will lead to a worse eco-friendly product recommendation and rating, a fewer number of product uses, and a smaller chance of continued use.

The independent variables for the experiment are attitude (for the attitude hypothesis), set-up difficulty, cleaning difficulty, and operation time (for the user-activity hypothesis). The dependent variables for the experiment include recommendation, continue to use, rating, number of uses, and change habit.

To determine the validity of the attitude hypothesis, a multinomial logistic regression analysis is performed on the data, just as it was in the initial pilot experiment. A logistic regression is done with the participants' attitude score as the independent variable and one of the five dependent variables. This process is repeated for each of the dependent variables. The results of the regression analysis for attitude are shown in Table 7.

Table 7. Regression analysis for attitude in consistent bottle experiment.

Dependent Variable	**Chi-Square**	**p-value**
Recommendation	11.63	0.48
Continue to use	9.00	0.17
Rating	17.18	0.51
Number of uses	19.41	0.37
Change habit	11.09	0.09

Based on the results of the regression analysis, there is significance found between environmental attitude and change habit. The dependent variable "change habit" is dichotomous, and the participants were asked whether they would replace disposable bottles with the product they tested. The "continue to use" variable nearly has significance, and since the sample size for this pilot is only eight, a larger sample size may lead to significance with this variable. This same regression analysis is performed to evaluate the user activity hypothesis, which includes set-up difficulty, cleaning difficulty, and operation time. All three of the variables are dichotomous and were asked as yes/no questions on the product evaluation survey. The exact questions asked of the participants are shown in the product evaluation form in Appendix E.

Of the eight participants, none of them reported that the product they tested was difficult to set-up or difficult to clean. The reported times for product set-up were all under 10 minutes, with the average being about 4 minutes. The longest time reported for cleaning time was 6 minutes, with the average at about 3 minutes. Only one of the eight participants reported that the product took too long to operate on a daily basis. The participant that reported this was testing the Brita pitcher, which was expected to have the longest operation time of all the products. The other participant testing the pitcher did not describe the operation time as being too long, but under the free-response question about what they liked least about the product, they said, “it took a long time to fill up the pitcher.”

Since there is no variation in answers for the set-up difficulty and cleaning difficulty, a regression analysis cannot be performed to evaluate these variables and whether they have an effect on the dependent variables. However, the participants were asked to report the amount of time it took them to set-up the product initially as well as the amount of time it took to clean. With these responses to the survey, a multinomial logistic regression analysis is performed on the data to determine whether the “set-up time” or “cleaning time” had any effect on the participants’ opinion of the product. The results for the set-up time regression is shown in Table 8 and Table 9 shows the cleaning time regression analysis.

Table 8. Regression analysis for set-up time.

Dependent Variable	Chi-Square	p-value
Recommendation	7.81	0.45
Continue to use	6.23	0.18
Rating	14.40	0.28
Number of uses	16.64	0.16
Change habit	8.32	0.08

Table 9. Regression analysis for cleaning time.

Dependent Variable	Chi-Square	p-value
Recommendation	8.86	0.55
Continue to use	9.00	0.11
Rating	14.40	0.50
Number of uses	16.64	0.34
Change habit	8.32	0.14

Based on the regression analysis for set-up time, there was significance found between set-up time and change habit. In addition, "continue to use" and "number of uses" are nearly significant. In the cleaning time regression, the variables of "continue to use" and "change habit" are nearly significant. Again, a larger sample size may mean that these variables prove to be significant with cleaning time. Based on the analyses for set-up time and cleaning time, the participants probably believe the set-up and cleaning of a product are important considerations when adopting an eco-friendly product. If the set-up or cleaning process is too lengthy, they will be less likely to exchange an eco-friendly product for its less environmentally conscious counterpart.

As part of the product evaluation survey, the participants were asked to record the amount of water bottles they typically drank in a week, with possible responses of 0-5, 6-10, 11-15, 16-20, or >20 bottles. This question helps to determine the participants' strength of habit when it comes to drinking from disposable bottles. A person that reports only drinking 0-5 bottles per week probably has a weak habit, while a person that drinks over 20 bottles per week probably has a stronger habit. Previously, when designing the experiment, it was not believed that strength of habit would have any effect on the dependent variables measured in the experiment. To ensure this is the case, a regression analysis is done with number of disposable bottles used per week, against the five dependent variables mentioned previously. The results for the analysis are shown in Table 10.

Table 10. Regression analysis for number of disposable bottles used per week.

Dependent Variable	Coefficient	Standard error	p-value
Recommendation	0.00	0.03	0.97
Continue to use	-0.02	0.02	0.36
Rating	0.05	0.05	0.37
Number of uses	-0.18	0.06	0.03
Change habit	0.04	0.02	0.12

The results indicate that the number of disposable bottles used per week has a significant, negative correlation with number of product uses for one week. In addition, the variable "change habit" is nearly significant. Pearson's correlation for the relationship between number of product uses and number of disposable bottles used per week is -0.765. This means that the people with a strong habit of drinking disposable water bottles probably do not accept using eco-friendly product alternatives as much as people that have a weaker habit. This result is also presented as a graph, shown in Figure 21.

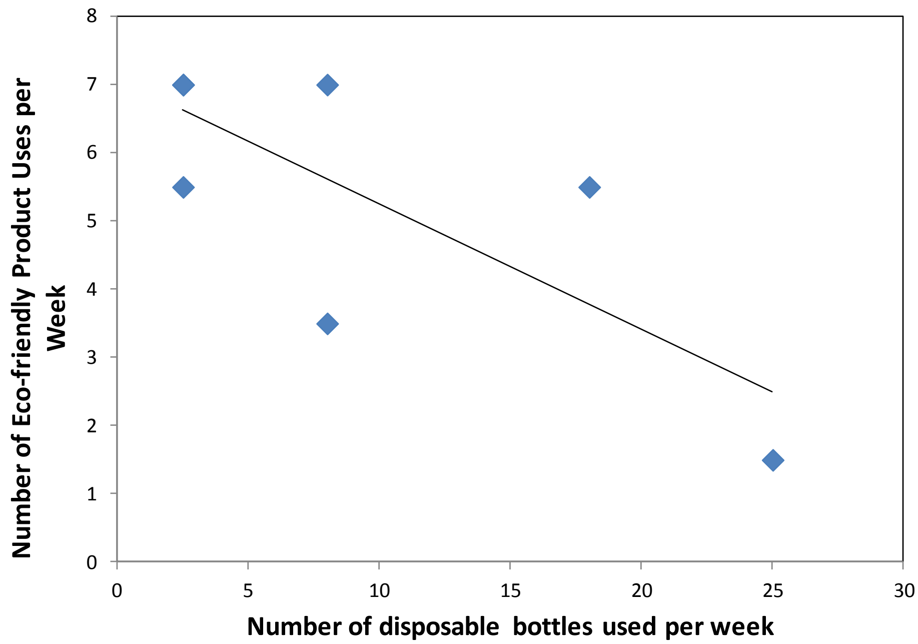

Figure 21. Correlation between # of disposable bottles used and # of product uses.

As in the initial pilot experiment, each of the products are compared based on recommendation, rating, number of uses, etc. This is done to determine whether any of the products scored particularly well, or poor when compared to each of the other products. The products used in the consistent bottle experiment scored higher on average in most of the categories than the products used in the initial pilot experiment. The average recommendation score for each product is shown in Figure 22.

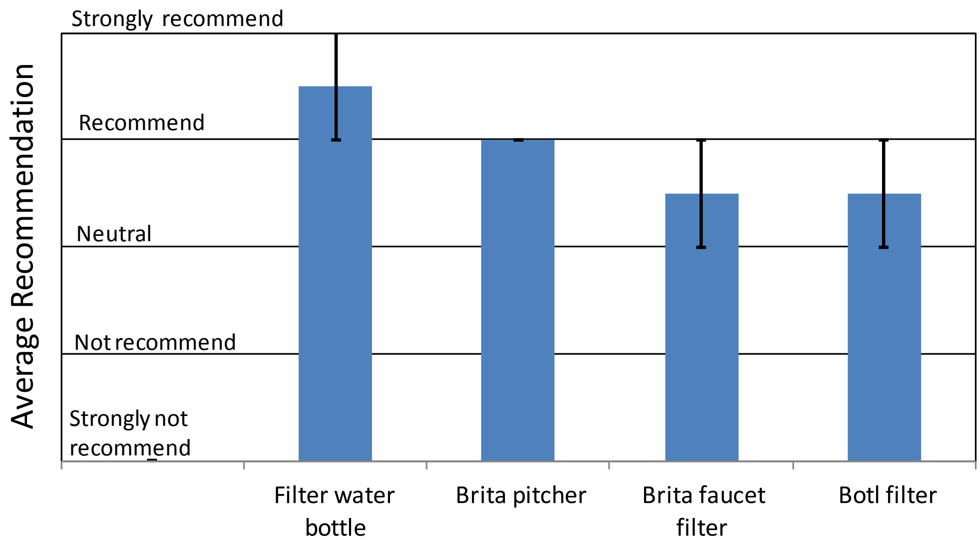

Figure 22. Average recommendation for consistent bottle products with +/- 1 standard error.

The products all have similar recommendation scores, with the average response being “recommend”, whereas in the initial pilot experiment, the participants mostly gave “neutral” responses for the recommendation question. The result for the product-rating question is given in Figure 23.

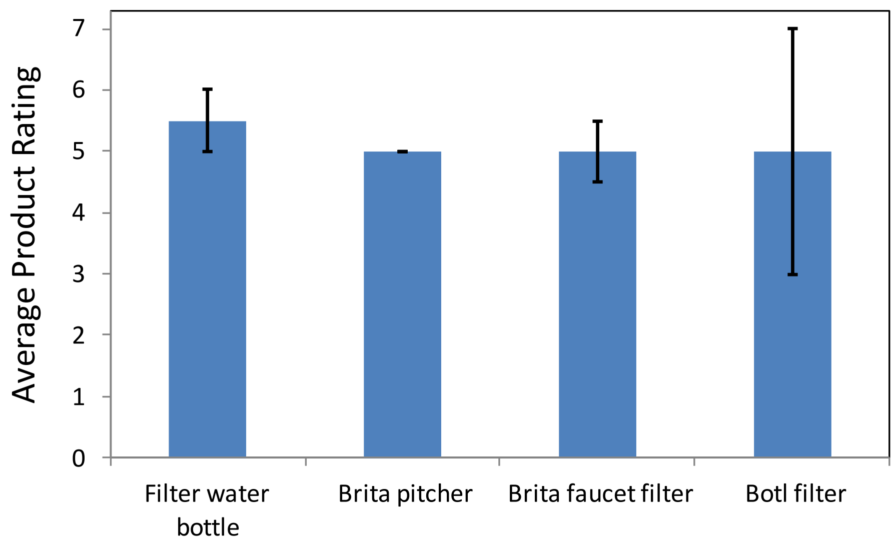

Figure 23. Average rating for consistent bottle products with +/- 1 standard error.

Again, the scores for each of the products are consistent for the product rating, with an average rating of around five on the 1-7 scale. This compares to the average of four for the products in the initial pilot experiment. The graph for the total success metric is shown in Figure 24. The total success is a measure that combines the recommendation score, product rating score, and continue to use score.

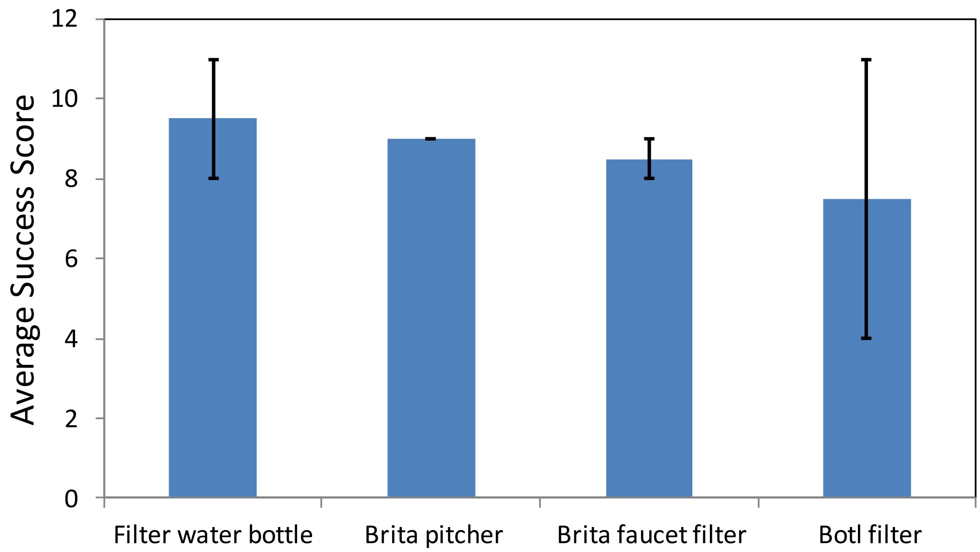

Figure 24. Average success for the consistent bottle products +/- 1 standard error.

The success scores are roughly even for each of the products with an average score of about an eight, which is higher than the initial pilot that had an average score of about six. The average number of uses for each of the products over the one week testing period is given in Figure 25.

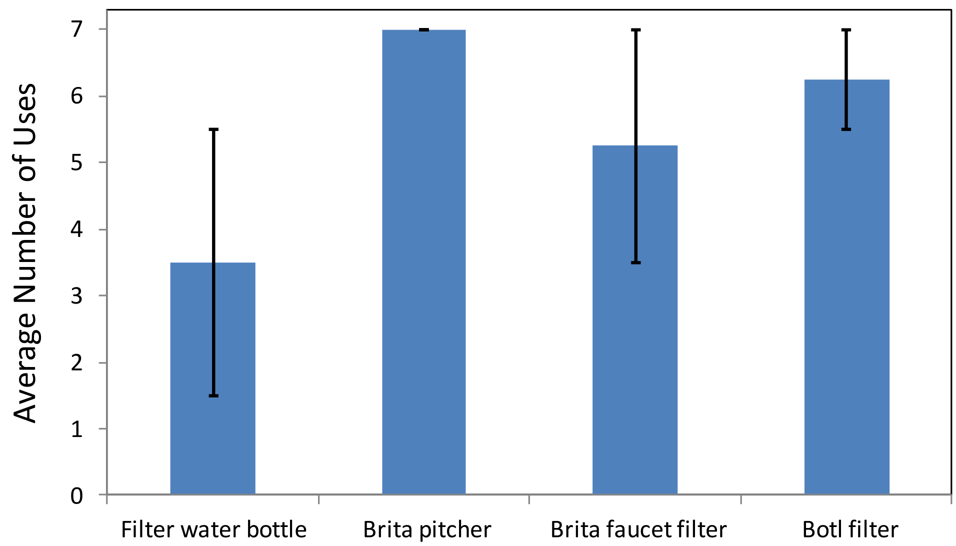

Figure 25. Average number of product uses +/- 1 standard error.

The responses for the number of uses very across the different product conditions, and there is a large error associated with both the Filter water bottle and the Brita faucet filter. This is probably due to the very small sample size, and the fact that there were only two participants per condition. In addition, it was shown previously that the number of product uses might depend on the strength of habit associated with drinking disposable plastic water bottles.

The participants were asked whether they would replace using disposable plastic water bottles with the new product they had tested. The result for this question is shown in Figure 26 as a percentage of participants that would replace for each of the four products.

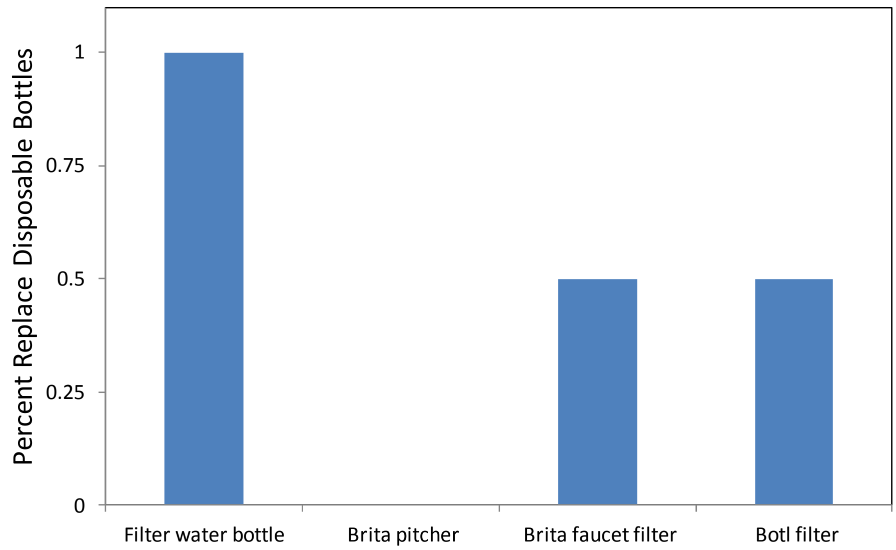

Figure 26. Percent of participants to replace disposable bottles.

Both of the participants with the filter water bottle reported that they would continue to use the product, and they would replace disposable bottles with the eco-friendly product. The two participants that tested the Brita pitcher reported that they would continue to use the product, but they would not completely replace using disposable water bottles with it. The pitcher is probably adequate for use at home when drinking from a glass, but it requires a lot of time when filling up the pitcher, waiting for the water to filter, and then pouring it into a water bottle, and for this reason, it is not a good substitute for disposable bottles. Both of the participants testing the pitcher claimed that the “long time to fill the pitcher” was the most negative feature of the product. There were mixed reviews for the Brita faucet filter and Botl filter. One of the participants testing the faucet filter claimed they would continue to use it, as well as replace disposable bottles with the product. The other participant claimed they would continue to use it, but not replace disposable bottles with it. This participant mentioned that they did not like the fact that the faucet filter was not “grab and go” like a disposable bottle, and that they had to chill the water bottle after filtering to have cold water. As for the Botl filter, one participant would continue to use the product and replace disposable bottles with it, while the other participant would not continue to use it and would not replace disposable bottles with it. The reason this participant ultimately did not like using the product was because they felt that it did not remove the bad taste from tap water.

As mentioned previously, the participants were asked to record the amount of time in minutes that it took them to set-up and clean the product. The results for set-up time are shown in Figure 27 and for cleaning time in Figure 28.

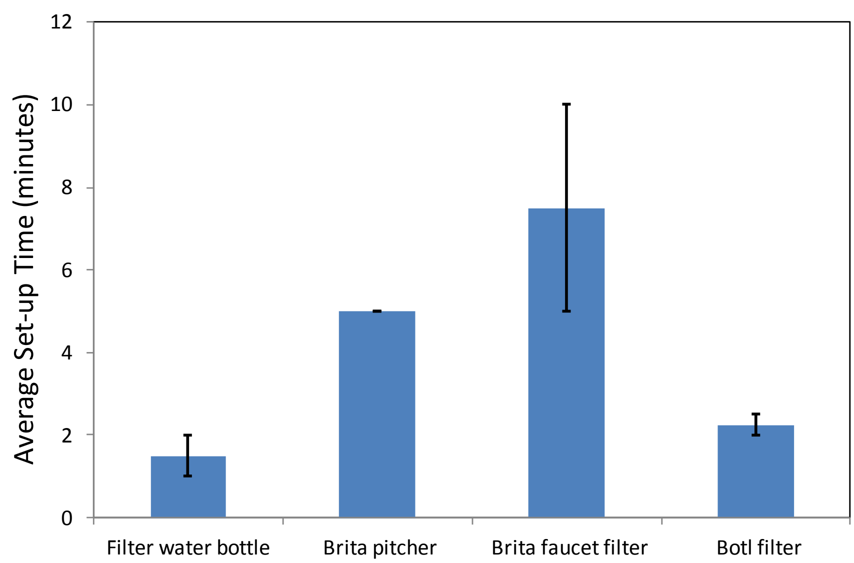

Figure 27. Average set-up time +/- 1 standard error.

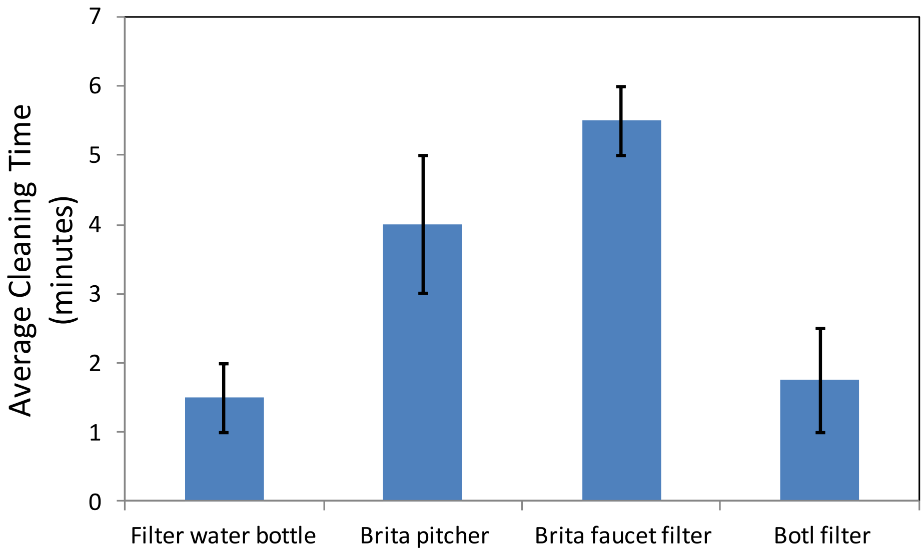

Figure 28. Average cleaning time +/- 1 standard error.

The Brita faucet filter has the longest set-up and cleaning time, followed by the Brita pitcher, and then the filter water bottle and Botl filter with similar times. These results were somewhat expected based on the initial analysis of product features.

Part of the open-ended section questionnaire includes listing the most favorable feature and most unfavorable feature of the product tested. By analyzing the responses to these questions, any extraneous and uncontrolled variables in the experiment become evident. The participant responses to this question are given in Table 11.

Table 11. Positive and negative features for consistent bottle products.

Positive product features	Negative product features
Can fill anywhere	Lid design
Save money	Bad taste/ long time to use
Fits on most sinks	Filter dust proir to using
Save money	Long time to use
Easy to use	Bad taste
Easy set-up	Long time to use
Easy to use	Bad taste

The responses are much better for the consistent bottle experiment than the initial pilot experiment because many of the uncontrolled variables such as aesthetics, bottle design, size, etc. are not evident in the participant responses. The responses that indicate undesirable variables are lid design and bad taste. Having the participants test the same water bottle was believed to eliminate many of the unwanted variables associated with the bottle, and it is evident that many of these variables have been eliminated from the experimental design. However, the participant that mentioned the lid design reported that they did not like the lid design of squirt style water bottles, and instead they preferred the lid of a disposable bottle that allows gulping of the water and less effort to drink on the user's part. To ensure that this type of variable does not interfere with the experimental design, it is essential to attempt to match as many of the features of the non-eco friendly product with the eco-friendly product being tested. For this experiment, a better product selection would include a water bottle that has an open-mouthed lid design that more closely resembles a disposable plastic water bottle.

Once the participants finished their surveys, they were asked a single interview question- What was your overall opinion about the product you tested? Did you like it or not and why? Of the eight participants, five of them said that they liked the product they tested overall. Two of the participants said they did not like it overall because they could not get over the fact that product did not get rid of the bad taste of tap water. This was the utmost important feature they desired, and the product did not perform well in that area so they would not use it as a replacement for disposable bottles. The other participant that did not like the product they tested was the student that mentioned the poor lid design.

Lessons learned

The consistent bottle experiment proved to have a more controlled experimental design than the initial pilot experiment, and most of the undesired variables were eliminated. However, a few minor details could potentially be changed to create a more controlled experiment. Changing the water bottle used in the experiment to one that has an open-mouthed lid design as opposed to the squirt-style lid design used in this experiment, would eliminate the variable of poor lid design (e.g. http://www.hydrosbottle.com, http://www.nubobottle.com). An example of this type of bottle is the nubo filter water bottle shown in Figure 29. This bottle closely resembles a typical disposable bottle, but has a filter on the bottom of the bottle.

Figure 29. Nubo filter water bottle.

The 321-water bottle used in the initial pilot has an open-mouthed lid design, but participants that tested this bottle mentioned that it was not very durable. Finding products that exist on the market and have all the essential features necessary for the experiment has proven to be a challenging part of testing eco-friendly products. Maintaining a controlled experiment, while still having enough variation of certain product features within the group of products is the greatest challenge. Extensive product research and testing prior to experimentation with participants is an extremely important part of designing a product testing experiment, such as the ones described in this research project.

It is important when testing eco-friendly product alternatives that the eco-friendly product features mimic their non-eco friendly counterparts as much as possible. For these water bottle experiments, the size, shape, and lid design are just some of the features that should resemble disposable plastic water bottles. If the eco-friendly product is similar to disposable bottles, then the participants will be affected less by these undesirable features.

In addition to the undesired variable of lid design, the fact that none of the participants reported difficult set-up or cleaning meant that the user hypothesis could not be tested adequately. In order to test this hypothesis, research should be done to find products with a more difficult set-up and cleaning process. It was believed that the faucet filter used in the experiment would be difficult to install and that the Botl filter would be difficult to clean, but unfortunately, this was not the case. A more in-depth initial analysis of the products would help determine whether enough variability exists between the products in set-up and cleaning difficulty. Pre-pilots should be performed to assess the difficulty for users to set-up and clean the various products. Another possibility is to adjust the question regarding difficult set-up and cleaning to involve a scale of difficulty instead of a yes/no type question. The complexity in designing this type of scaled question is that every person's perception of difficulty is different from one another, so it is difficult to compare scores. For this case, additional questions may be needed to assess the participants' perception of difficult set-up and cleaning.

CHAPTER IV

PAPER TOWEL EXPERIMENT

Introduction

The default option is a behavior change tool described in psychology literature and states that people typically use a default option if it is available to them. This behavior change theory has the potential to be very powerful when applied to the realm of product design, especially eco-friendly product design. People tend to behave in whichever manner requires the least amount of work on their part. They choose to take the path of least resistance. This means that if a person is faced with a choice, and a default option is available, most of the time people will choose the default option regardless if it is the best option (Thaler and Sunstein 2008). A product designer wishing to create an eco-friendly product can use this behavior change theory to ensure the default option is the most environmentally conscious one.

The Design with Intent method described in previous text gives “Defaults” as one pattern under the errorproofing lens. An image of the defaults card is given in Figure 30. This behavior change design method is commonly seen in the computer science field among software designers.

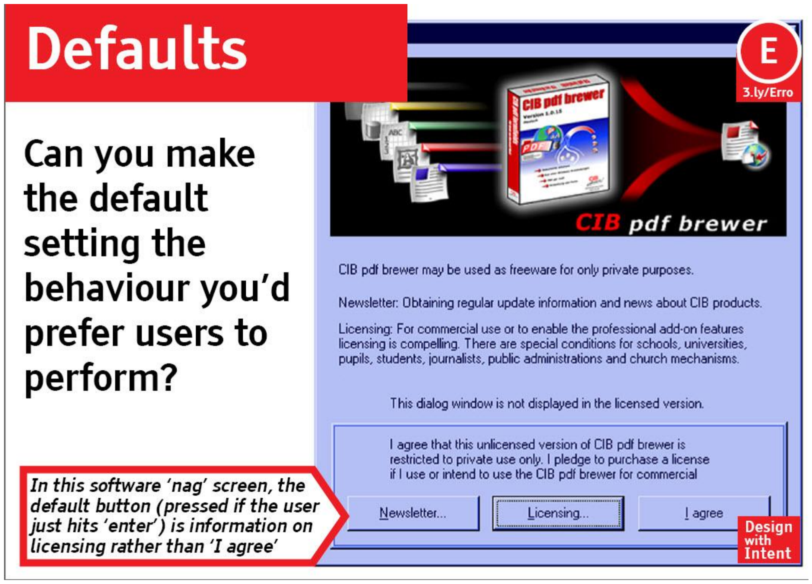

Figure 30. Default card in the Design with Intent method cards (Lockton et al. 2010).

Experimental method

Automatic paper towel dispensers (Georgia Pacific, model # ADS200B) will be used to test the behavior change theory of the default option. The length of paper towel from these dispensers that is released to the user can be adjusted to three different lengths- 8 inches, 12 inches, or 16 inches. The more eco-friendly option is to set the dispenser to release a small amount of paper towel so that paper is not wasted. However, if the length of towel released is not enough to dry the users' hands, then they may tear off another paper towel. In this case, the user's needs may override the default option. If the needs of the user are met, then the default option will usually apply. In the case that the user's needs are not being met to such an extreme level, the default option will probably not apply. A picture of the automatic paper towel dispensers used in the experiment is shown in Figure 31.

Figure 31. Photo of paper towel machine.

Hypotheses

In this experiment, it is predicted that when the paper towel lengths are set to either 12 inches or 16 inches, the user will choose the default option and only take a single paper towel. When the paper towels are set to a length that is too short-8 inches, the users will not choose the default option and will use multiple sheets of paper towels. If these hypotheses are correct, then the number of paper towels used for the short condition will be nearly double the number of towels used for the long condition.

Procedure

There are six total restrooms, three women's and three men's, which have been monitored for a total of three weeks for this pilot experiment. Each restroom is assigned a certain length of paper towel according to the following designations:

Short- 8 inches

Medium- 12 inches

Long 16 inches

The assigned length of paper towel remains in the bathroom for one week, and is then changed to a different assigned length. The schedule for each bathroom and their corresponding length of paper towel is given in Figure 32 along with a diagram of the bathroom assignments in Figure 33.

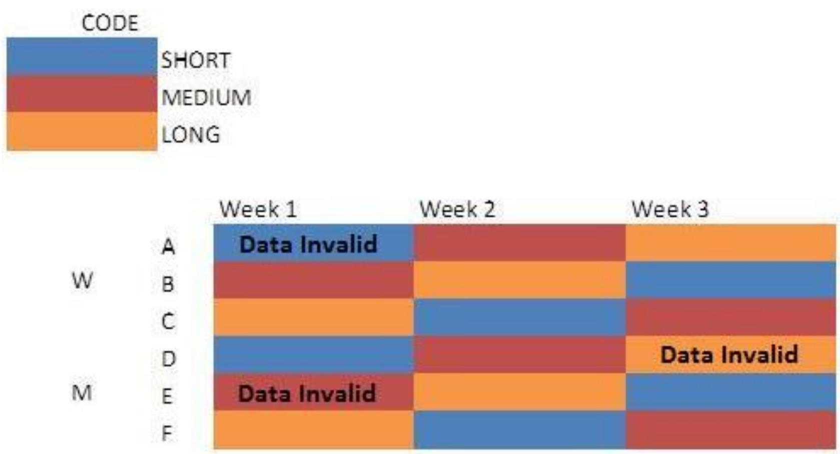

Figure 32. Timeline for each bathroom and its corresponding length.

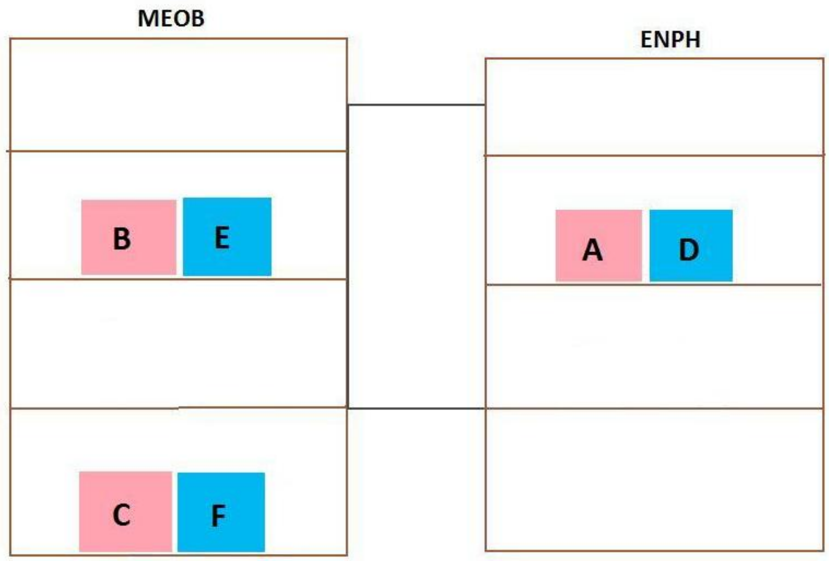

Figure 33. Diagram of bathroom assignments.

Before the experiment began, the current length of paper towel was measured for each dispenser and noted. On the Monday of each week, the original weight and radius of the paper towel roll is measured. The radius and weight are measured five times each to insure results that are more accurate. Then, on the following Monday, the weight and radius measurements are collected again to determine the amount of paper towel used. This process is repeated for each of the three weeks. During the week, the paper towels are checked to make certain they do not run out and the machines are running correctly daily. If the radius of the roll is below 1.5 inches, then the roll is replaced. The data collection sheets used for the experiment are given in appendix H. A more detailed, systematic procedure is given in the following text.

Detailed testing procedure

Supplies: Tape measure, scale, calipers, dispenser key, paper towel rolls

1. Measure the current length of paper towel that the dispenser gives and write down (do this for week 1 only).

2. Use the key to open the dispenser and adjust the length setting of the dispenser to the appropriate length according to the schedule provided (either S,M, or L).

3. Remove the paper towel roll and place on scale to weigh. Record the weight on the data sheet in the “original weight” box. Repeat this measurement five times.

4. Use the calipers to measure the thickness of the paper towel roll. Record the radius on the data sheet in the “original radius” box. Repeat this measurement five times.

5. Place the paper towel roll back in the dispenser and lock it. Ensure that the paper towels are dispensed at the correct length.

6. Repeat steps 1-5 for each of the six bathrooms.

7. Check the bathrooms daily to ensure the dispensers are working correctly and are dispensing the correct amount of paper towels. If the roll is too small (below 1.5 inches in radius), replace the current paper towel roll with a new one. If this is the case, make sure to record the new roll’s weight and radius measurements in the boxes provided on the check-up sheet.

One week later:

1. Use the key to open the dispenser and remove the paper towel roll.

2. Place the roll on the scale and determine the weight of the roll. Record this number on the data sheet in the “Final weight” box. Repeat this measurement five times.

3. Use the calipers to measure the thickness of the roll. Record the radius on the data sheet in the “Final radius” box. Repeat this measurement five times.

4. Get a brand new roll. Then, repeat steps 3-5 from above with the new paper towel roll.

5. Place the paper towel in the dispenser and adjust the length setting to the new length according to the schedule. Lock the dispenser and make sure it is giving the correct length of paper towel.

6. Repeat steps 1-5 for each of the six bathrooms.

During testing, the paper towels are monitored every day to ensure that the machines are working correctly and have not run out of paper towels. Especially for the A and D bathrooms since they are subject to high traffic flows. Once a day, the machines are inspected and the radius of the roll is measured and recorded to keep track of the rate of paper towel loss. If a roll is getting to low or has run out, then a new roll is used. The original weight and radius of the new roll is measured and recorded and then replaces the old roll. During analysis, the change in weight and radius will be added together for all the rolls used in the one-week period.

Since it would be very difficult and time consuming to directly determine the length of paper towels used each week, a correlation can be found between the weight, radius, and length. A paper towel roll identical to the ones used in the experiment can be used to determine this correlation. The original weight and radius of the roll is measured, and then it is unrolled and a piece of the towel is ripped off. The length of this piece is measured with a tape measure. The weight and radius is then measured again. This process is continued until all the paper towel has been removed from the roll. From these measurements, the actual length of the paper towel on the roll at any point can be calculated by subtracting the amount of paper towel removed from the total length of towel. Then, a graph is created with the data points of length versus weight and length versus radius. A best-fit curve to the data gives an equation that best represents the correlation between length, weight, and radius.

Results

Correlation analysis

The process to find the relationship between length, weight, and radius is completed twice to determine statistical accuracy. The data for the correlation analysis is given in Appendix I. It is unknown whether the weight or radius measurements will give a more accurate prediction of the length of paper towel on the roll. However, it is known that the possibility for human error is higher with the radius measurements because there is some degree of give that the paper towels have when measuring the radius with calipers. Since the thickness of a paper towel is so small, even the slightest human error in measuring could throw off the length prediction.

Both length versus weight and length versus radius are graphed and their corresponding best-fit trend lines are found. The two graphs created from the weight versus length data are shown in Figure 34 and Figure 35.

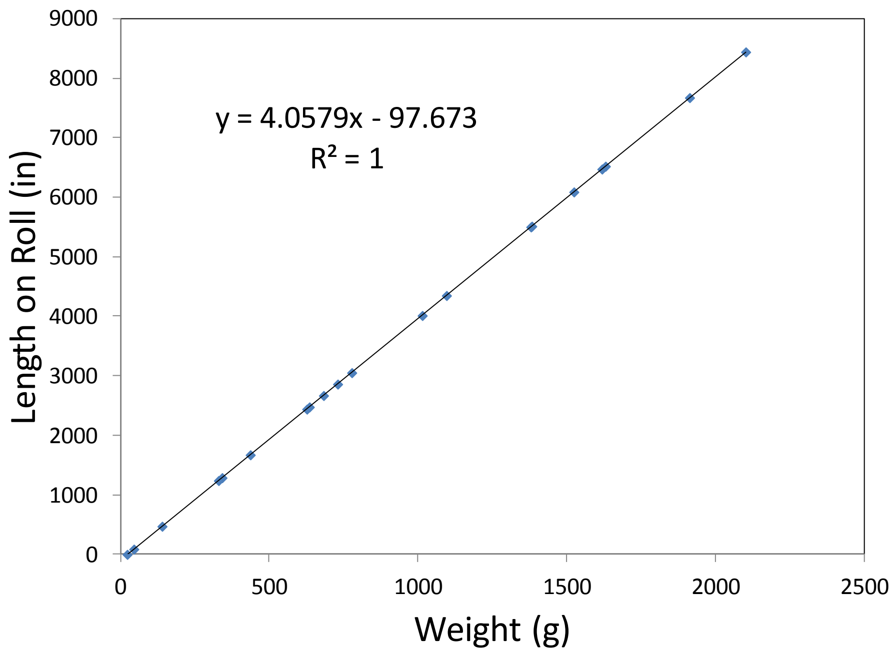

Figure 34. First linear fit from measured weight versus length.

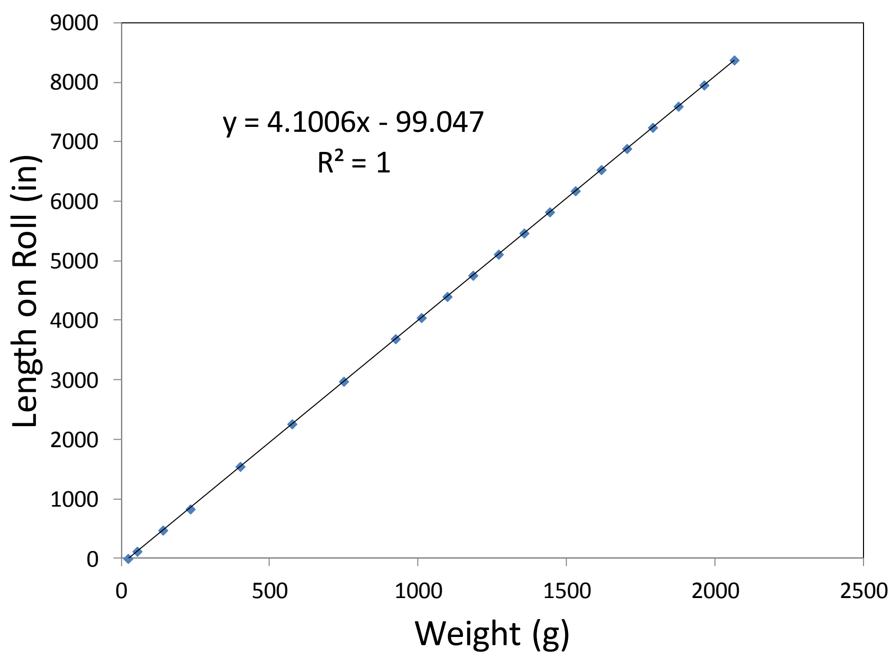

Figure 35. Second linear fit from measured weight versus length.

The data fit very well to the linear trend lines for the graphs, with a $R^2 = 0.99$ for each of the linear equations. Based on the equations generated, the predicted length is calculated and then compared to the measured length. The largest percent error for the linear comparison of weight versus length is about 0.43% for the first linear fit and about 0.26% for the second linear fit. For simplicity, the two equations are averaged to product a single linear relationship for weight versus length, which is shown in Equation 1.

$$y = 4.07925x - 98.36 \tag{1}$$

The two graphs created to model the relationship between measured radius and length are shown in Figure 36 and Figure 37.

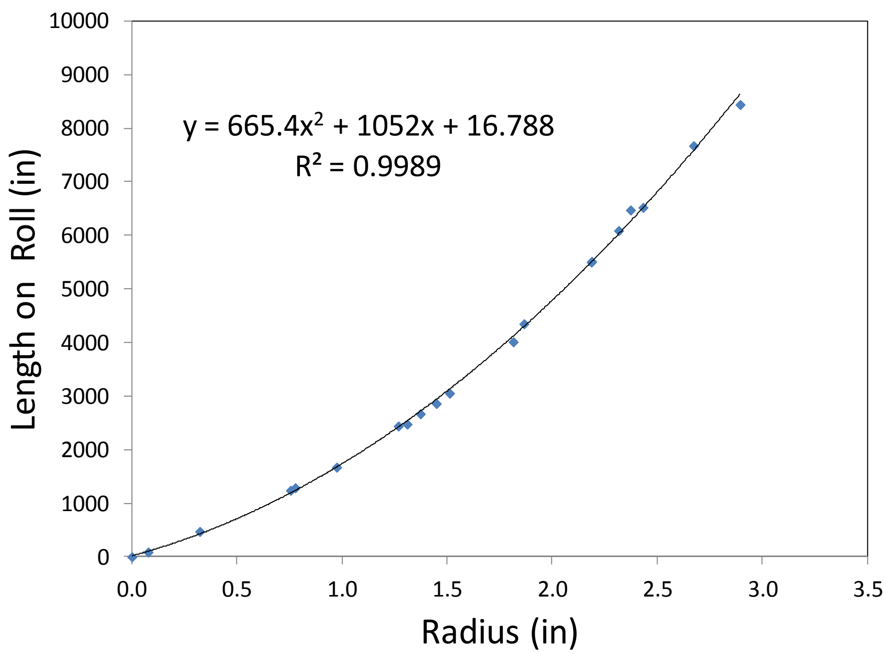

Figure 36. First polynomial fit for measured radius versus length.

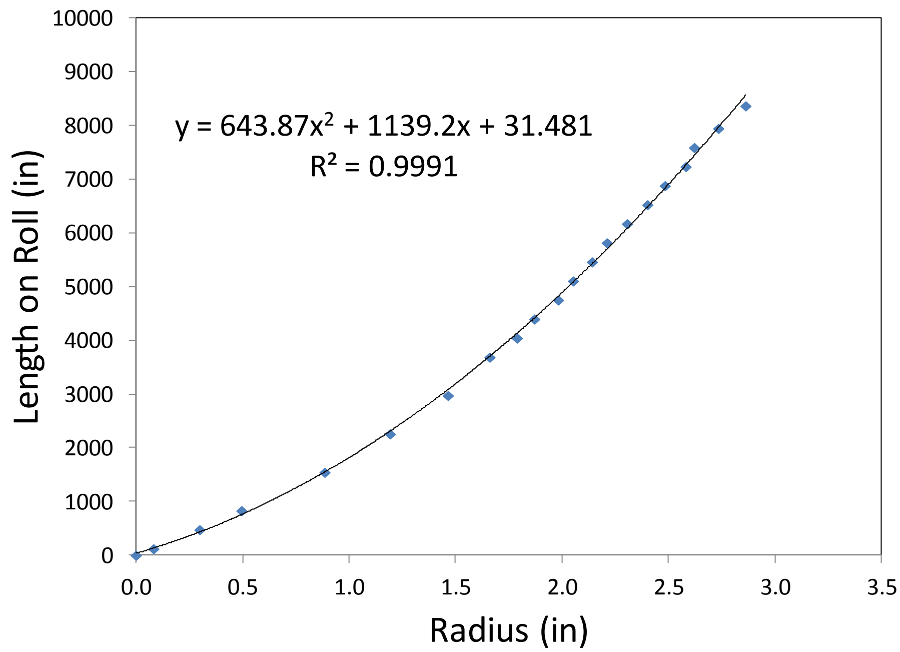

Figure 37. Second polynomial fit for measured radius verses length.

The second order polynomials are good fits for the radius versus length data, with R^2 = 0.9989 and R^2 = 0.9991, but they are not as good of a fit as the linear ones for weight versus length. The predicted length based on the radius is calculated and the corresponding percent error is found between the actual length and the predicted length. This value is about 4.14% for the radius data, which is much higher than the weight data that has a percent error of about 0.43%. Because of this, it is decided that the weight is a better predictor of the length of paper towels. The max error for the weight based length predictions is 17.2 inches, which is about 2 lengths of paper towels for the short condition and only one length for the long condition.

Evaluating research question

Over the three-week long experiment, the consumption of paper towels was monitored for the short, medium, and long conditions. A complete data table for the paper towel experiment is given in appendix J. The initial and final weights of the paper towel rolls are used to calculate the change in length, with Equation 1 given previously. Due to issues with the paper towels running out during testing, the data from restroom A, D, and E are neglected. The graphs for the length of paper towels used in one week for restrooms B, C, and F are given in Figure 38, Figure 39, and Figure 40, respectively.

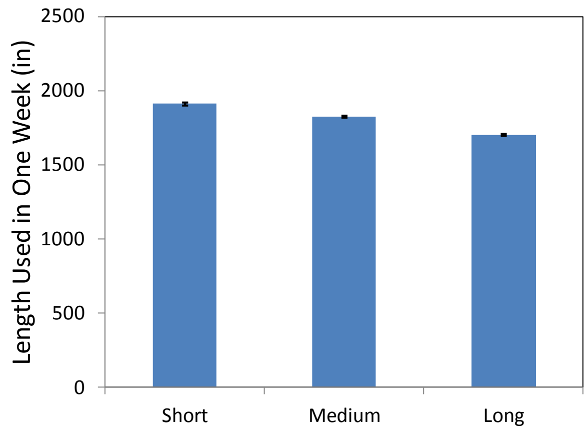

Figure 38. Length used in one week for restroom B with +/- 0.43% error bars.

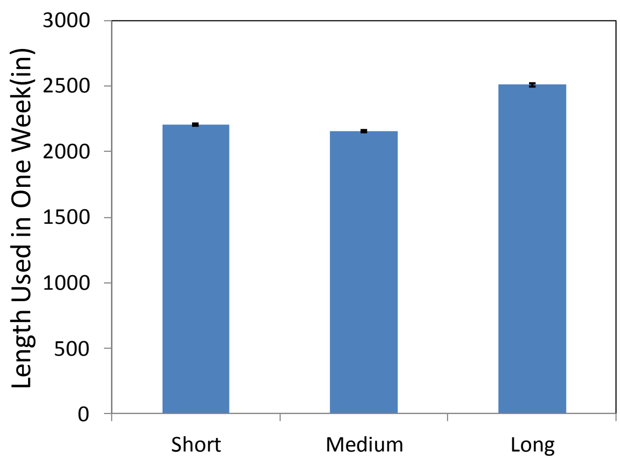

Figure 39. Length used in one week for restroom C with +/- 0.43% error bars.

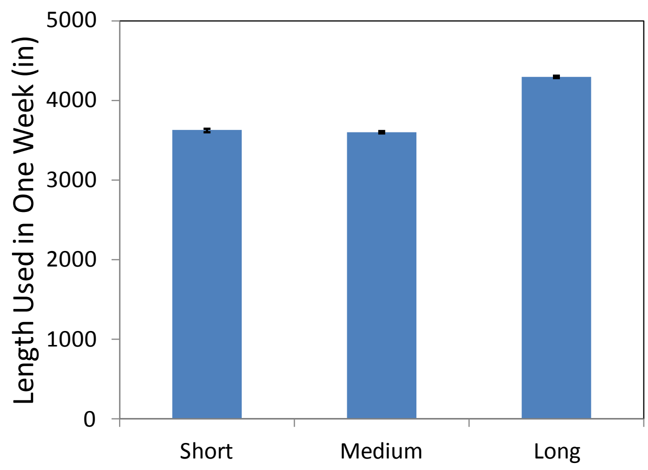

Figure 40. Length used in one week for restroom F with +/- 0.43% error bars.

The data for the average length of paper towels used in all three restrooms for the short, medium, and long conditions is given in Figure 41.

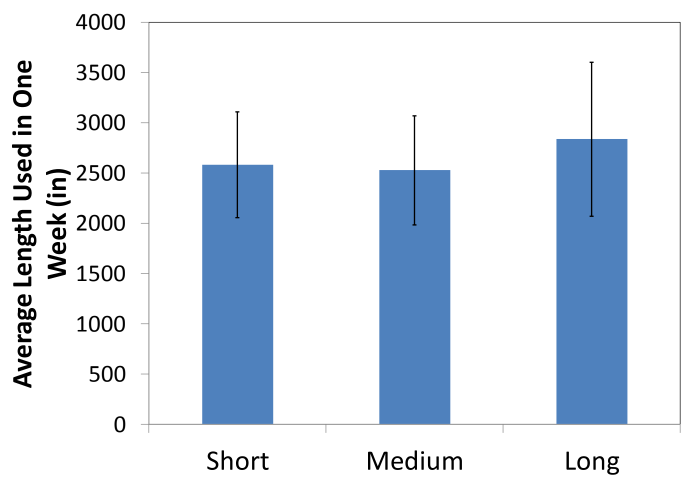

Figure 41. Average length used in one week for B, C, and F with +/- 1 standard error bars.

In order to determine whether the experimental hypothesis is correct, the number of paper towels used for each condition must be calculated. The number of paper towels is found by dividing the length used in one week by the length of paper towel dispersed for the condition (8 for short, 12 for medium, and 16 for long). The graphs for the number of paper towels used for restrooms B, C, and F are given in Figure 42, Figure 43, and Figure 44, respectively.

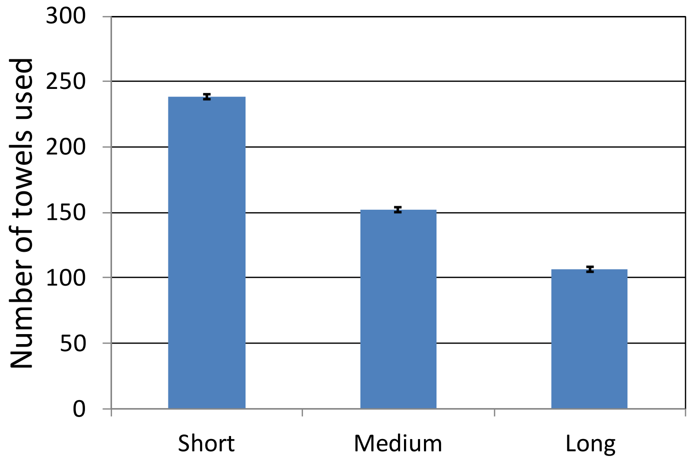

Figure 42. Number of towels used for restroom B with +/- 2 error bars.

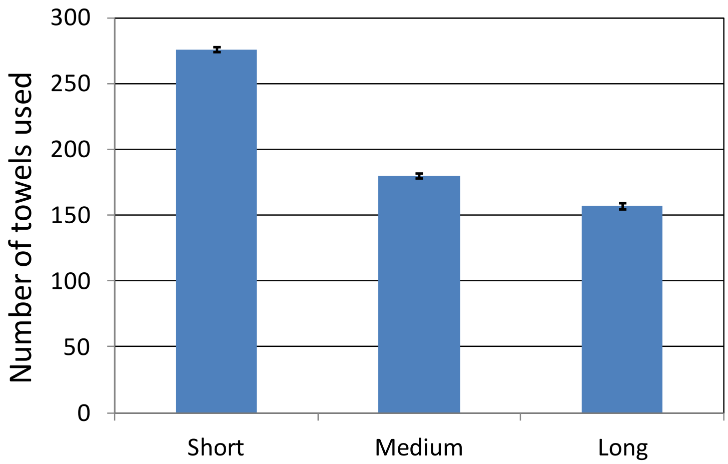

Figure 43. Number of paper towels used for restroom C with +/- 2 error bars.

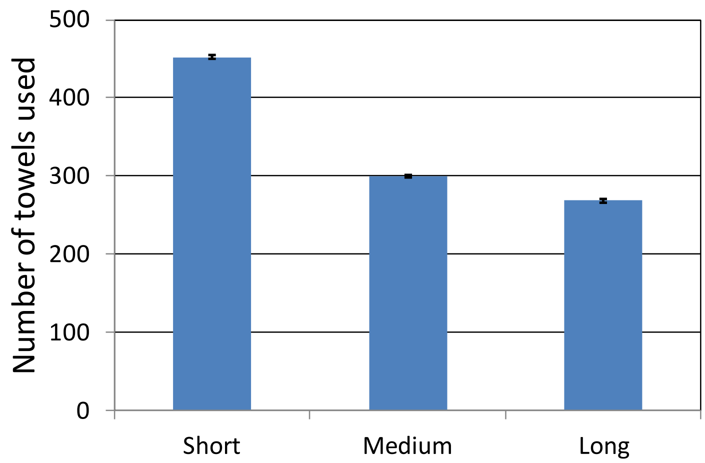

Figure 44. Number of paper towels used for restroom F with +/- 2 error bars.

The same trend for the number of towels used exists for all three restrooms, where the long condition uses roughly half the number of towels as the short condition. This result agrees with the predicted result that the default option does not hold true for the short condition. The short length of paper towel is not adequate to dry the users' hands, so they ignore the default option and take multiple sheets of paper towels.

CHAPTER V

SUMMARY AND CONCLUSIONS

For this research, three pilot experiments were conducted to examine a few causes of poor eco-friendly product acceptance. The first two experiments tested alternative products to disposable plastic water bottles, such as filter water bottles, filter pitchers, and faucet filters to name a few. Two hypotheses were developed and tested- the attitude hypothesis and the user activity hypothesis. The attitude hypothesis states that a person with a positive environmental attitude will lead to better eco-friendly product recommendation and rating, greater product uses, and a greater chance of continued use. The user activity hypothesis states that a product with difficult set-up or cleaning will lead to a worse product recommendation and rating, fewer product uses, and a smaller chance of continued use. Participants tested the alternative products to disposable water bottles for one week and then returned to complete two surveys. These surveys measured variables such as environmental attitude, product recommendation and rating, number of uses, continued use, and many others. The third pilot experiment tested the theory of default options, which has the potential to be a powerful tool when designing eco-friendly products. This theory was tested with an experiment involving the use of automatic paper towel dispensers. The lengths of dispensed paper towels were adjusted to either short, medium, or long lengths and the corresponding usage was measured after one week periods.

The results of the first two pilot experiments show that environmental attitude, set-up difficulty, and cleaning difficulty are indeed factors in the participants' acceptance of the eco-friendly products. The results from the paper towel experiment indicate that users obey the rule of defaults, unless their needs are not being met at an extreme level. Not only were many of the results significant from these pilots, but the lessons learned from these experiments will also help to develop a framework for product testing with human subjects.

There have been many lessons learned from the initial pilot experiment. The most important realization is that when testing eco-friendly alternatives to products, it is essential that many of the features of the eco-friendly alternative must function just as well as the features of the non eco-friendly counterpart. In the initial pilot experiment, features such as aesthetics, bottle design, and lid design affected the participants in a negative way. These product features are undesirable in the experimental design because they are not being controlled for. When the eco-friendly product resembles the non eco-friendly alternative as much as possible, the participants are less likely to be affected by these undesirable variables present in the products.

While the consistent bottle experiment controlled for many more variables than the initial pilot experiment, there are still issues that should be resolved. Two of the independent variables tested in the experiment, set-up difficulty and cleaning difficulty, were unable to be analyzed because there was not enough variability within the products used for the experiment. This is quite different from the initial pilot experiment, when too much variability existed between the products and many variables were not accounted for. It is evident from these experiments that a careful balance exists between controlling for as many variables as possible, while still maintaining enough diversity in the variables being measured. The lesson learned in the consistent bottle experiment is that initial product testing is crucial, prior to allowing participants to test them. Pre-pilots should be done to produce a more in-depth insight to the set-up and cleaning difficulty of the products. Several people can be timed to determine how long it takes them to set-up and clean the products. Observations of the set-up and cleaning process can also be done to determine whether any particular step is difficult for the user.

A comprehensive list of guidelines to follow when using human subjects to test eco-friendly products is given below:

- **Match product features-** the eco-friendly product being tested should mimic many of the features of their non eco-friendly counterparts. Users may be caught up on the aesthetics of the product, or some other uncontrolled variable. Try to only have variation in the features being tested and measured.

- **Extensive product research-** lengthy product research and testing is extremely important. Purchasing and testing many different products prior to the experiment gives a better idea of features being measured. Pre-pilots should be conducted to ensure enough variation exists between the products in whatever variable is being measured.

- **Develop a product survey-** the product evaluation survey should be developed through pre-pilots to ensure the questions are easy to read and understand. It should include questions that establish the participant's environmental habits associated with the product being tested. Brainstorming should be done to determine all possible variables that may affect product acceptance, and then appropriate questions may be developed to measure these variables. If there are uncontrolled variables present in the experimental design, they will most likely become evident in the responses to the product evaluation survey.

In psychology literature, it is said that attitude tends to mold people's perceptions of the world around them, and even possibly encourages certain behaviors. Based on previous research done by Esposito and Linsey (2012), it is believed that a person's environmental attitude affects their acceptance of eco-friendly products. Thus, if a person has a poor attitude toward the environment, it is hypothesized that they would have a negative view of eco-friendly products. This negative view in turn affects how often they use the product, whether they recommend it or not, whether they continue to use it, etc. The results from this research indicate that environmental attitude may be a factor that affects eco-friendly product acceptance. Based on the two pilot experiments performed with alternative water bottles, the regression analysis for attitude has shown that it may relate to whether the user will continue to use it in the future. The regression analysis also shows that attitude influences whether the user replaces disposable bottles with the eco-friendly product they tested.

In addition to the attitude hypothesis, Esposito and Linsey (2012) found that initial product set-up and adding user activities may affect product acceptance. These assumptions are tested in this research through the user activity hypothesis. For this hypothesis, three measurable variables have been developed- difficulty of product set-up, difficulty of product cleaning, and time to operate on a daily basis. The variables are assessed with the product evaluation survey that the participants completed after product testing. All three variables are dichotomous, and were asked as yes/no questions on the survey. The results from the initial pilot experiment indicate that the set-up difficulty affects the user's opinion of the product. The product rating, total product success metric, and the number of product uses during the week are all significant variables in the regression analysis of set-up difficulty.

The results from the consistent bottle experiment reveal that the product set-up time may affect whether the user replaces disposable bottles with the eco-friendly option they tested. Set-up time is nearly significant for variables such as “continue to use” and “number of product uses”. The regression analysis for cleaning time indicates that cleaning time is nearly significant for the “continue to use” variable and the “change habit” variable. Another interesting result found with the consistent bottle experiment is that the number of disposable bottles drank per week is strongly correlated to the number of eco-friendly product uses. This implies that the strength of habit associated with drinking disposable plastic bottles greatly affects the acceptance of an eco-friendly alternative.

The sample sizes for the initial pilot experiment and consistent bottle experiment are very small, yet they produced many significant results. This shows that with a larger sample size, it is probable that the variables that were nearly significant will prove to be significant. This also shows that the effect size of these variables is very high and it is very likely that user behavior can be changed.

The results from the paper towel experiment agree with the anticipated result that users do not obey the rule of defaults if their needs are not met at such an extreme level. The most eco-friendly setting for automatic paper towel machines is to dispense a small amount of paper towel so paper is conserved. However, based on the results of the experiment, a length that is too short will lead to the users' taking multiple sheets, thus the short setting is not eco-friendly. The medium setting is likely the most eco-friendly because the users' obey the default setting by only taking one sheet and it saves more paper than the long setting.

Future work

There is great potential for future experiments involving eco-friendly product testing. The data in this thesis demonstrate great potential for influencing user behavior through effective product design. The research presented here is only the beginning of this type of experimental testing that involves real participants with real products, while still maintaining highly controlled conditions. Since there are few to no reports of this type of experiment, it is a difficult process to develop an experimental method that adequately tests the experimental hypotheses. However, the lessons learned during the process are profound and help to develop a framework for testing eco-friendly products.

In the future, the consistent bottle experiment could be carried out as a full experiment with a larger sample size. A few changes should be made, such as changing the water bottle to an open-mouthed design instead of the squirt style used in the pilot experiment. In addition, the set-up and cleaning difficulty questions on the survey should be adjusted from dichotomous to a scaled question. Additional questions may need to be asked to determine the participant's perception of what is difficult to set-up or clean.

This type of experimental design could also be applied to other eco-friendly products, rather than just water bottles. A control group would test a non eco-friendly product, while the treatment group tests an eco-friendly alternative to the non eco-friendly product.

Another potential avenue for research in this area is empirical research on eco-friendly products that exist on the market. The features of successful eco-friendly products could be determined by examining many products. A metric to determine “successful” products from “unsuccessful” products would have to be generated. The product features would be compared to determine whether similarities exist, and appropriate design principles would be developed from the data.

Potential also exists for the future of the paper towel experiment. Since the experiment conducted was a pilot experiment, a full experiment could be performed. Additional restrooms could be analyzed and the time of testing could be increased from one week to two weeks per condition.

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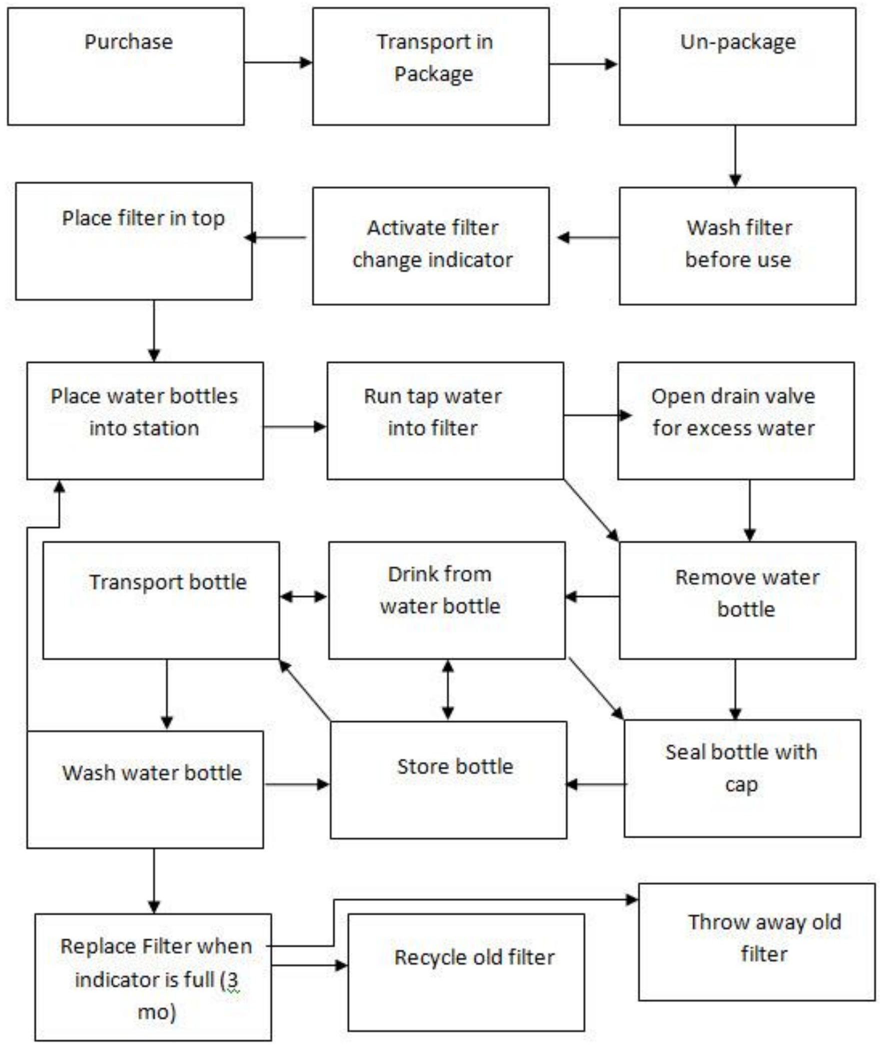
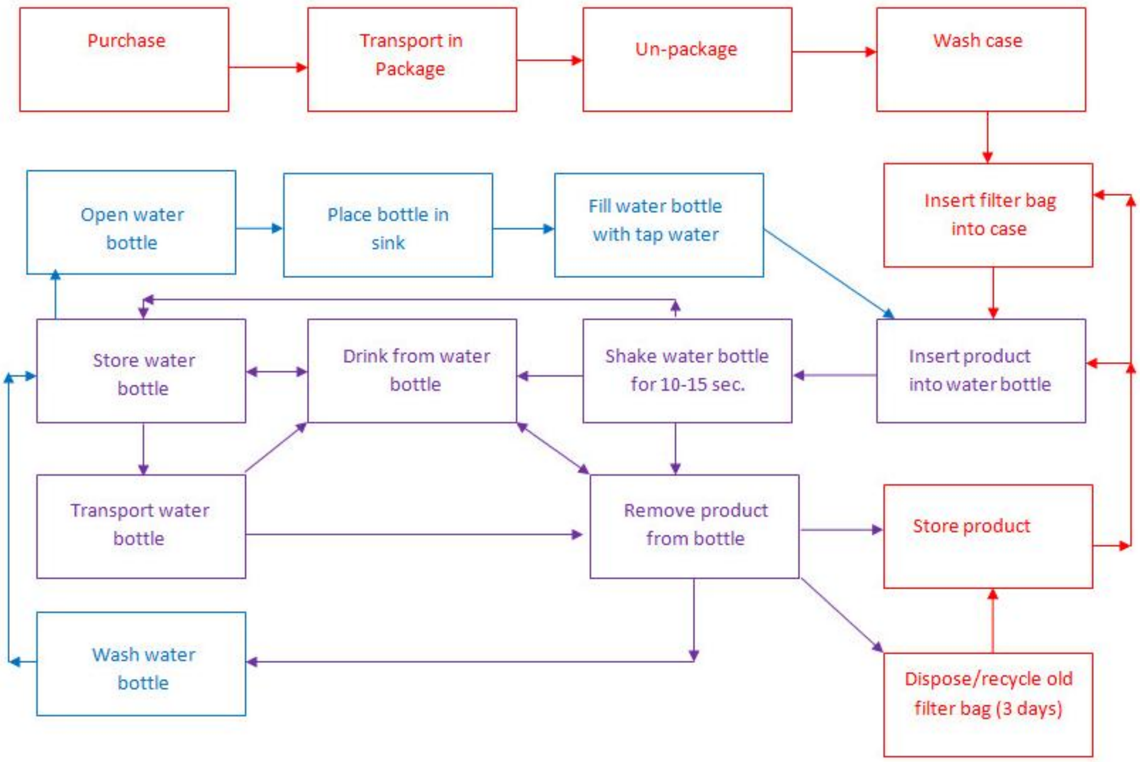
APPENDIX A

ACTIVITY DIAGRAMS

Filtrete Water Station

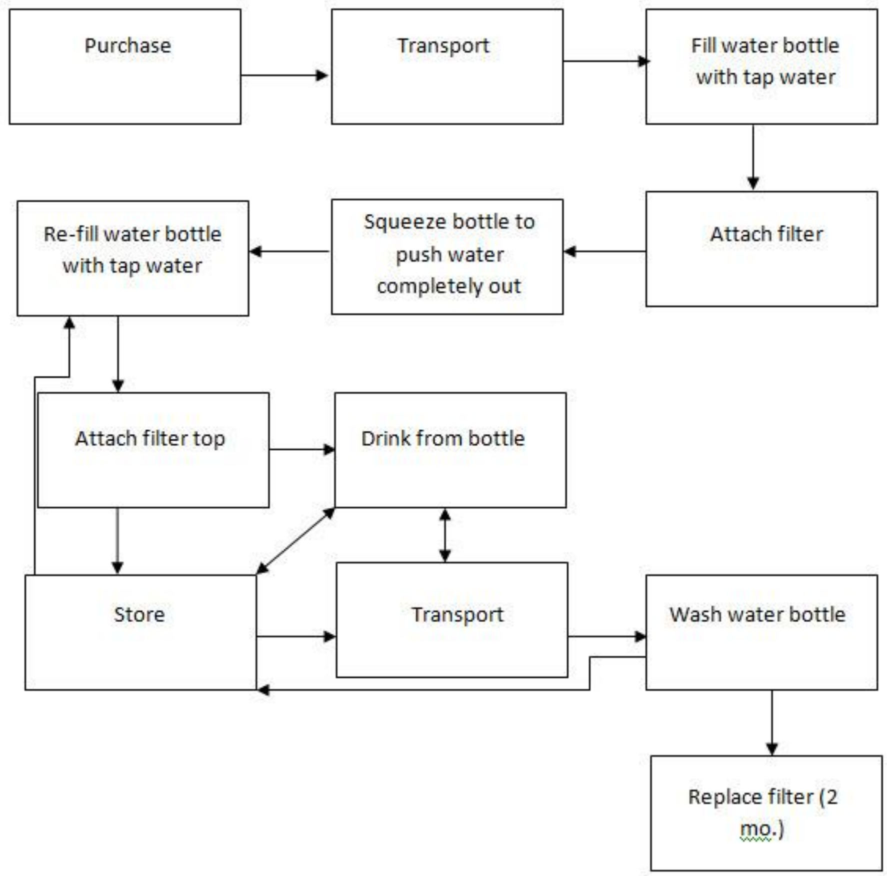


Botl Filter

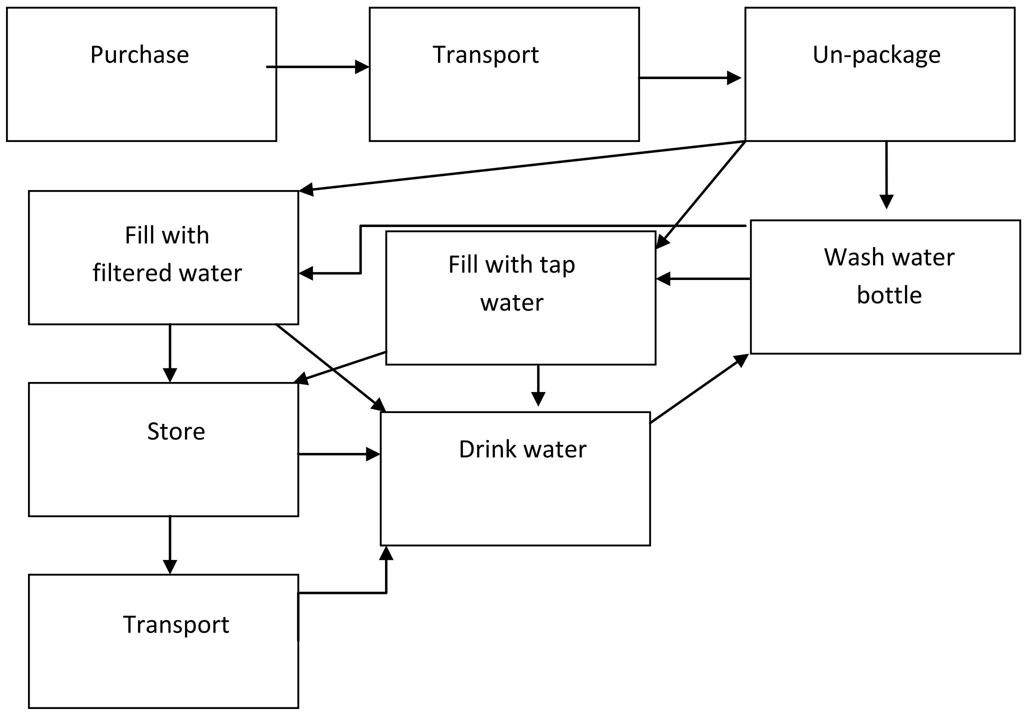


Legend
Botl Filter
Water Bottle
Both

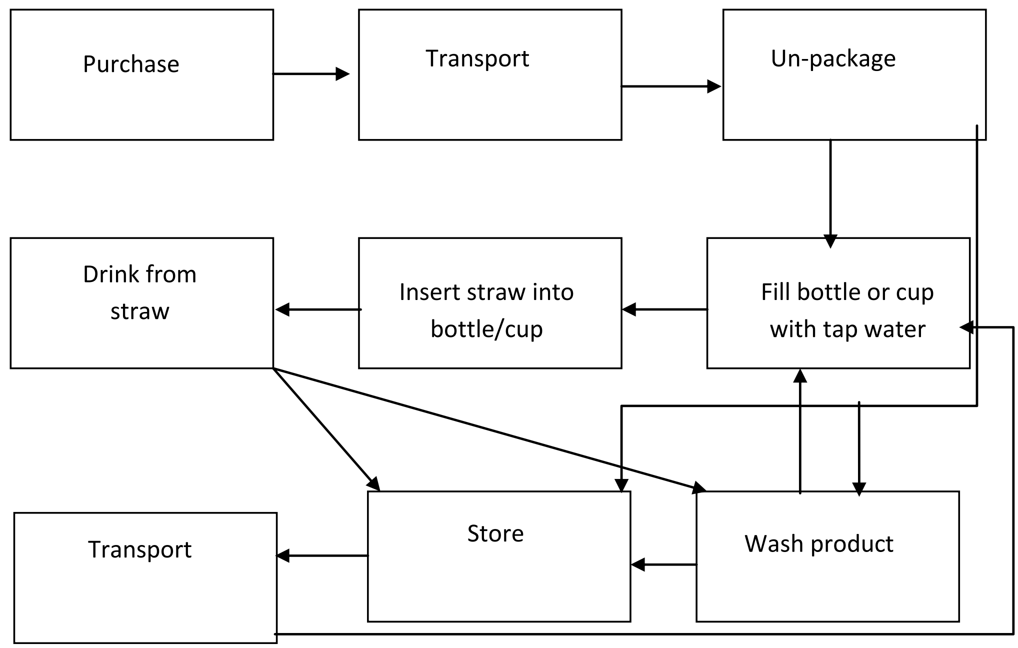
Brita Water Filter Bottle



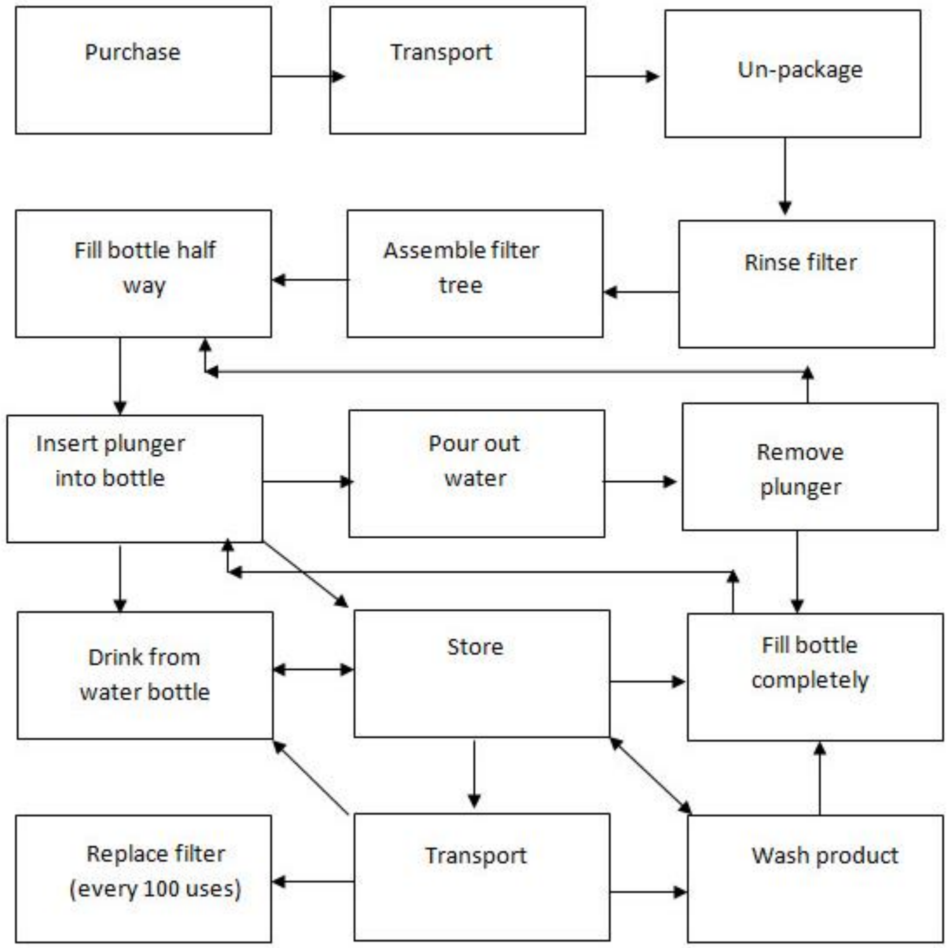
Metal Water Bottles



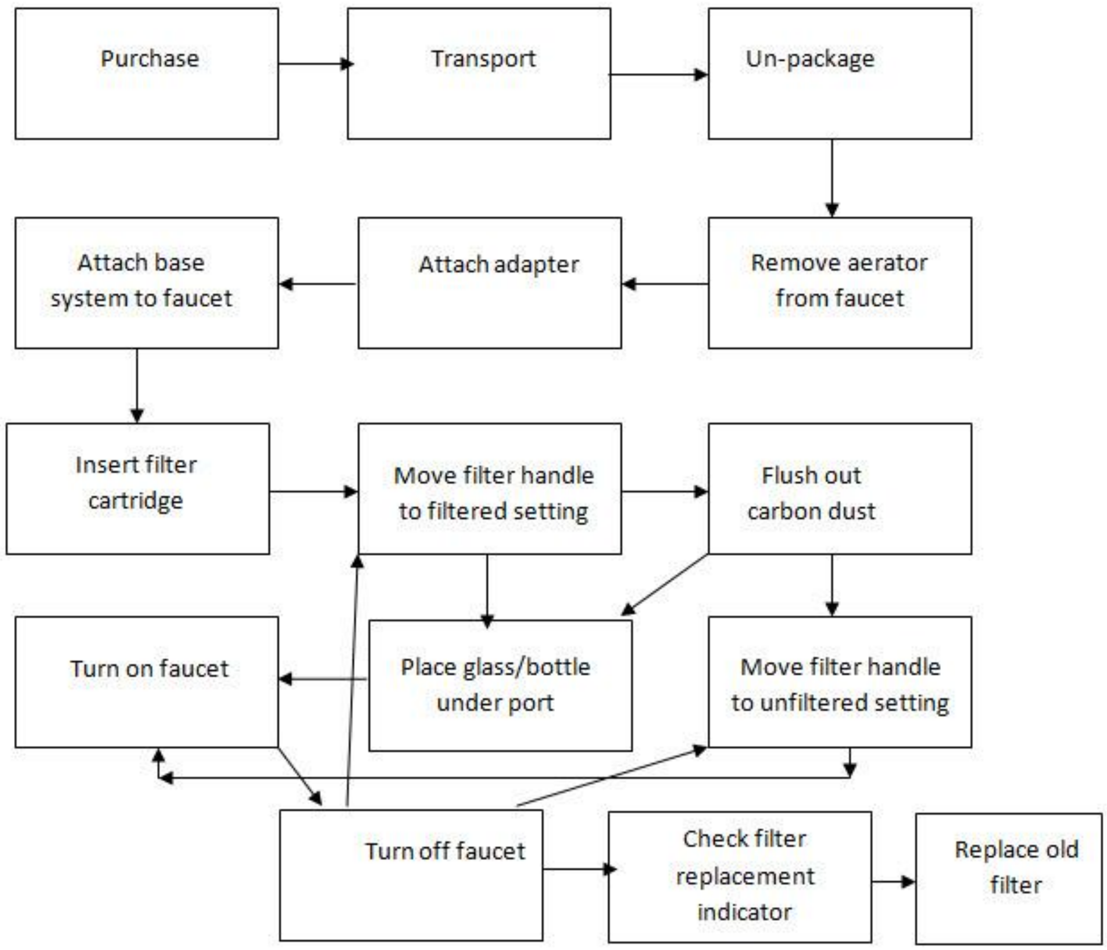
Water Filter Straw



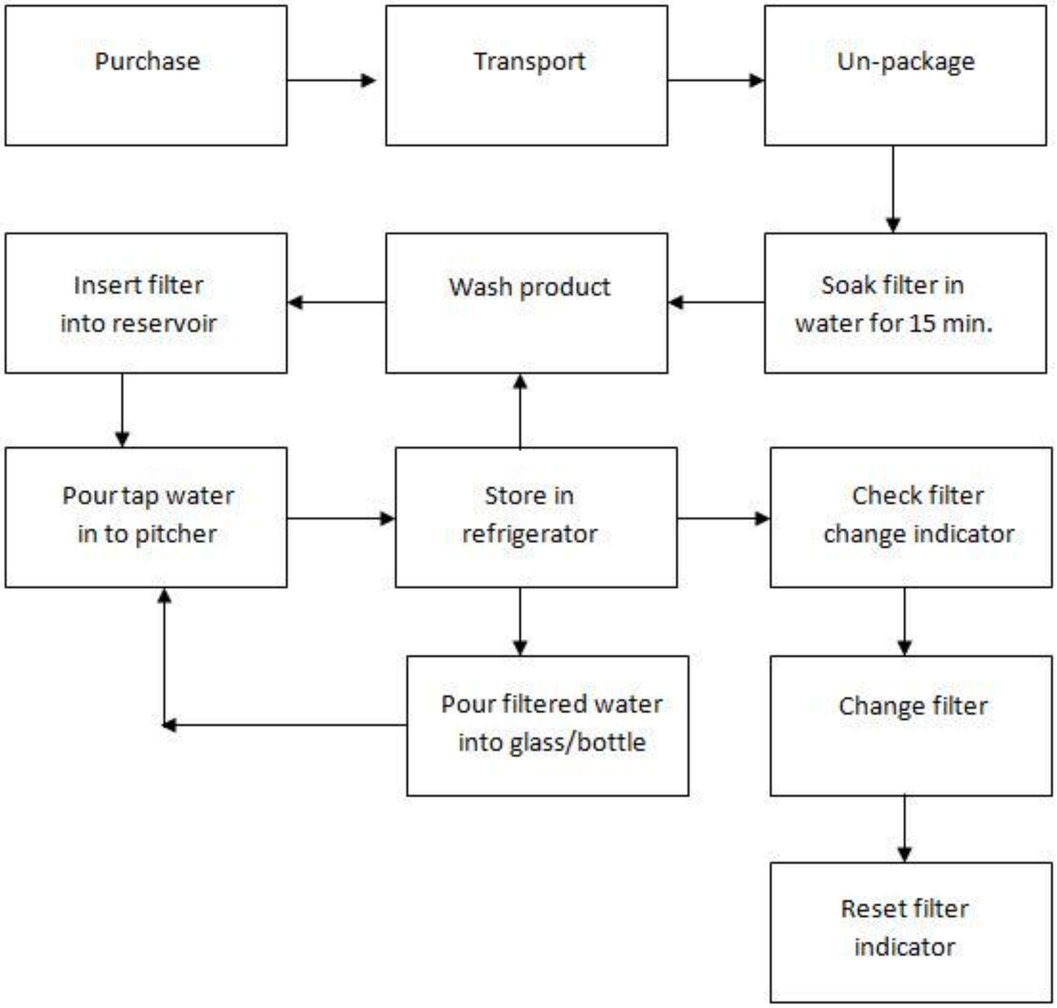
321 Water Bottle



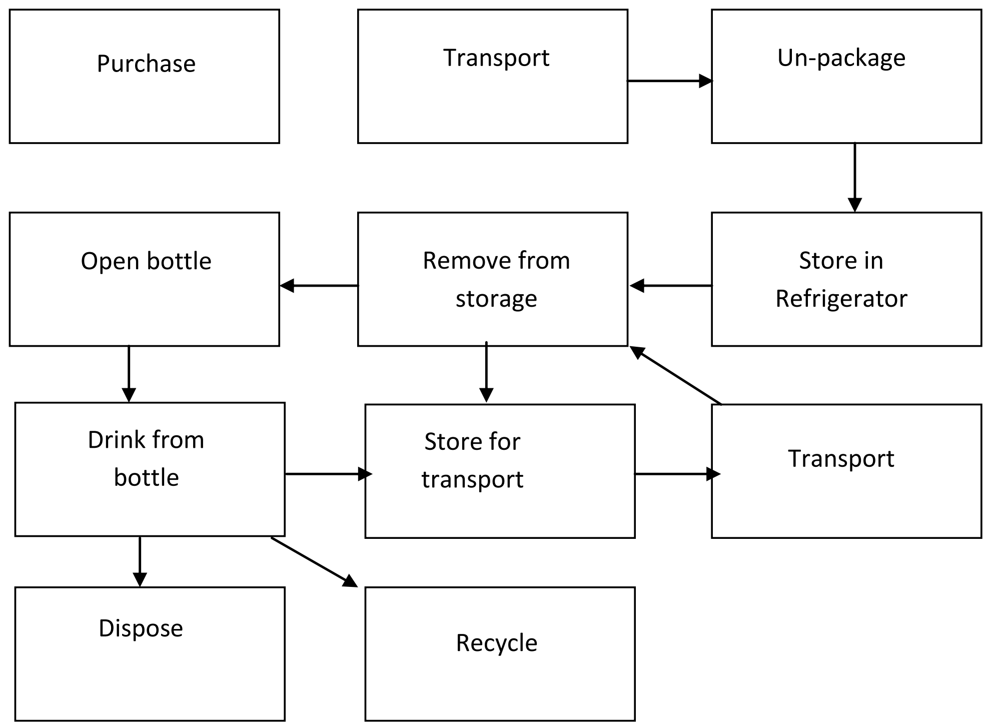
Faucet Filter



Filter Water Pitcher



Conventional Plastic Water Bottle



APPENDIX B

EXPERIMENT SCRIPT

<u>Check list:</u>

Part 1:

- Participant consent forms (2 per participant)
- My contact information
- Participant-condition sheet
- Condition count sheet
- Pen

Part 2:

- payment slips (if needed)
- Demographic survey
- Product evaluation sheet
- Pen

1. <u>Consent</u>

"Hello and thank you for taking time to participate in this research study. You are being asked to participate in a research study on engineering design. You are not required to participate in this study and may end your participation at any time."

"In this experiment, you will be asked to take home one eco-friendly product to use for one week. After that time, we ask that you return and complete two short surveys. Now, please read the consent form in front of you. If you have any questions, feel free to ask."

Wait until all of the participants have finished reading to proceed with the experiment.

"If you agree to participate please sign the form and keep the second copy for your records."

Wait for participants to sign the consent forms.

Collect the consent forms.

"Your efforts will be compensated when you bring back the products after a week. You must agree to not discuss any aspects of the study with other engineering students at Texas A&M until after May 1, 2013 since this will bias the results. "

2. *Product Instructions*

Get the correct product and put in front of participant.

"Here is the product that you will be testing for the week. The instructions are in the product box if you wish to read them before use."

Hand the participant my contact information.

"Here is my contact information along with the date you will need to return to complete the surveys. I will contact you with a reminder before you need to return."

3. *Wrap it up*

"Thank you for your participation and please remember to not discuss this study with your classmates until after May 1, 2013 since this will bias the results. If you have any questions about the study I can answer them at this time."

Make sure to get the phone number and e-mail address from participants before they leave.

4. *Product evaluation survey*

"Hello and welcome back. Thank you again for your participation in this study. I am now going to ask you to complete a few short surveys. The first one is a product evaluation survey. "

Give the participant the product evaluation survey.

"Please complete this survey at this time. If you have any questions about the survey, please feel free to ask."

Wait for them to complete the survey and then collect it.

Now give them the demographics survey.

"This is a demographics questionnaire. Please complete it at this time. If you have any questions about the survey, please feel free to ask. If you do not feel comfortable filling out any part of the survey, you may leave the question blank."

Wait for them to complete the survey and then collect it.

Write the participant ID # at top of each evaluation sheet. And the participant ID # on the demographics sheet.

5. *<u>Compensation</u>*

For paid participants:

Write the expiration date and participant number on the slip and give the participant their payment slip.

“Here is your payment slip. To receive your payment, please follow the instructions on the slip. Remember that this payment slip expires one month from today’s date.”

For unpaid participants:

“Thank you for your participation. I will insure that you are on the list to receive your extra credit in your design class.”

APPENDIX C

DEMOGRAPHIC SURVEY

Part 1

<u>Listed below are statements about the relationship between humans and the environment. For each one, please indicate whether you STRONGLY AGREE, MILDLY AGREE, are UNSURE, MILDLY DISAGREE, or STRONGLY DISAGREE with it:</u>

	Strongly Agree	**Mildly Agree**	**Unsure**	**Mildly Disagree**	**Strongly Disagree**
1. We are approaching the limit of the number of people the earth can support.	☐	☐	☐	☐	☐
2. Humans have the right to modify the natural environment to suit their needs.	☐	☐	☐	☐	☐
3. When humans interfere with nature it often produces disastrous consequences.	☐	☐	☐	☐	☐
4. Human ingenuity will insure that we do NOT make the earth unlivable.	☐	☐	☐	☐	☐
5. Humans are severely abusing the environment.	☐	☐	☐	☐	☐
6. The earth has plenty of natural resources if we just learn how to develop them.	☐	☐	☐	☐	☐
7. Plants and animals have as much right as humans to exist.	☐	☐	☐	☐	☐
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations.	☐	☐	☐	☐	☐
9. Despite our special abilities humans are still subject to the laws of nature.	☐	☐	☐	☐	☐
10. The so-called “ecological crisis” facing humankind has been greatly exaggerated.	☐	☐	☐	☐	☐
11. The earth is like a spaceship with very limited room and resources.	☐	☐	☐	☐	☐

	Strongly Agree	Mildly Agree	Unsure	Mildly Disagree	Strongly Disagree
12. Humans were meant to rule over the rest of nature.	☐	☐	☐	☐	☐
13. The balance of nature is very delicate and easily upset.	☐	☐	☐	☐	☐
14. Humans will eventually learn enough about how nature works to be able to control it.	☐	☐	☐	☐	☐
15. If things continue on their present course, we will soon experience a major ecological catastrophe.	☐	☐	☐	☐	☐

Part 2

In terms of your own behavior, circle whether each statement is TRUE or FALSE:

True False I guess I've never actually bought a product because it had a lower polluting effect.

True False I'd be willing to ride a bicycle or take the bus to work in order to reduce air pollution.

True False I feel people worry too much about pesticides on food products.

True False I keep track of my congressman and senator's voting records on environment issues.

True False I would probably never join a group or club which is concerned soley with ecological issues.

True False It frightens me to think that much of the food I eat is contaminated with pesticides.

True False I have never written a congressman concerning the pollution problems.

True False I would be willing to use a rapid transit system to help reduce air pollution.

True False It genuinely infuriates me to think that the government doesn't do more to help control pollution of the environment.

True False I have contacted a community agency to find out what I can do about pollution.

True False I'm not willing to give up driving on a weekend due to a smog alert.

True False I feel fairly indifferent to the statement: "The world will be dead in 40 years if we don't remake the environment."

True False I don't make a special effort to buy products in recyclable containers.

True False I'm really not willing to go out of my way to do much about ecology since that's the government's job.

True False I become incensed when I think about the harm being done to plant and animal life by pollution.

True False I have attended a meeting of an organization specifically concerned with bettering the environment.

True False I would donate a day's pay to a foundation to help improve the environment.

True False I'm usually not bothered by so-called "noise pollution."

True False I have switched products for ecological reasons.

True False I would be willing to stop buying products from companies guilty of polluting the environment, even though it might be inconvenient.

True False I get depressed on smoggy days.

True False I have never joined a cleanup drive. (example: a neighborhood clean-up)

True False I'd be willing to write my congressman weekly concerning ecological problems.

True False When I think of the ways industries are polluting, I get frustrated and angry.

True False I have never attended a meeting related to ecology.

True False I probably wouldn't go house to house to distribute literature on the environment.

True False The whole pollution issue has never upset me too much since I feel it's somewhat overrated.

True False I subscribe to ecological publications.

True False I would not be willing to pay a pollution tax even if it would considerably decrease the smog problem.

True False I rarely ever worry about the effects of smog on myself and family.

Part 3

Please circle your best possible answer:

All things considered, would you classify yourself as an environmentalist? YES NO NOT SURE

Part 4

<u>Listed below are potential life-style adjustments. Indicate whether you DO THIS, are WILLING TO DO THIS, are RELUCTANT TO DO THIS, or are OPPOESD TO THIS:</u>

	I do this	I am willing to do this	I am reluctant to do this	I am opposed to do this
Use nontoxic products	☐	☐	☐	☐
Practice water conservation	☐	☐	☐	☐
Separate garbage	☐	☐	☐	☐
Turn down heat in winter	☐	☐	☐	☐
Eat less meat	☐	☐	☐	☐
Drive less	☐	☐	☐	☐
Restrict use of private autos	☐	☐	☐	☐
Encourage two-child families	☐	☐	☐	☐
Support international programs	☐	☐	☐	☐

Part 5

<u>Multiple demographic questions are listed below.</u>

<u>Please fill in the blanks:</u>

1. **Gender:** ______________

2. **Age:** ________________

<u>Please circle your level of education:</u>

3. **Education:**

Freshman Sophomore Junior Senior Graduate

APPENDIX D

PRODUCT EVALUATION SURVEY- INITIAL PILOT EXPERIMENT

Please circle your best answer:

1. **Would you recommend this product to a friend or family member?**

Strongly Recommend	Recommend	Neutral	NOT Recommend	Strongly NOT Recommend

2. **Will you continue to use the product?**

Yes No Maybe Not sure

3. **All things considered, what would you rate the product on a scale of 1-7, where one is the worst product you have ever used and seven is your absolute favorite product you have ever used?**

1	2	3	4	5	6	7
Worst						Absolute Favorite

4. **What is your absolute favorite product you have ever used?** ___________________________________

5. **Do you typically use disposable plastic water bottles?** Yes No

6. **If you answered YES, do you think the product you tested will change this habit? (If you answered NO to the previous question, skip this question)**

Yes No

7. **Did you find it difficult to set up the product before use?** Yes No

8. **Did you find it difficult to clean or maintain the product?** Yes No

9. **Approximately, how often did you use the product in the past week?**

Daily 5-6 days 3-4 days 1-2 days Never

Please record your response in the blanks provided:

10. How long did it take you to learn how to use the product? ___________________________________

11. What did you like MOST about the product? Please explain why.

____

____

____

12. What did you like LEAST about the product? Please explain why.

____

____

____

13. Did the product function as expected? If not, why?

____

____

____

14. Did using the product work well with your lifestyle or did you have to force yourself to use the product? Please explain.

____

____

____

15. Did using this product influence you to be more eco-friendly in other aspects of your life? If yes, please describe.

____

____

____

APPENDIX E

PRODUCT EVALUATION SURVEY- CONSISTENT BOTTLE EXPERIMENT

1. **Approximately, how many disposable plastic water bottles do you typically use? Please circle one.**

0-5 per week   6-10 per week   11-15 per week   16-20 per week   >20 per week

2. **What brand (or brands) do you typically buy?** ____

3. **Do you ever refill your disposable plastic bottles? If so, how? (Ex: from kitchen sink, from water fountain, etc.)**

____

____

4. **In addition to using disposable plastic water bottles, do you use non-disposable water bottles or other water filtration products? If so, what kind?**

____

____

PART 2

1. **Would you recommend this product to a friend or family member?**

Strongly Recommend	Recommend	Neutral	NOT Recommend	Strongly NOT Recommend

2. **Will you continue to use the product?**

Yes   No   Maybe

3. **All things considered, what would you rate the product on a scale of 1-7, where one is the worst product you have ever used and seven is your absolute favorite product you have ever used?**

1	2	3	4	5	6	7
Worst						Absolute Favorite

4. **What is your absolute favorite product you have ever used?** ________________________________

5. **Approximately, how often did you use the product in the past week?**

Daily   5-6 days   3-4 days   1-2 days   Never

6. **Do you think you will replace the disposable plastic water bottles that you normally use with the product you tested?**

Yes   No

7. **Did you find it difficult to set up the product before use?**

Yes No

8. **Approximately, how long did it take you to set up the product before use (in minutes)?**

____

9. **Did you find it difficult to clean the product?**

Yes No

10. **Approximately, how long did it take you to clean the product (in minutes)?**

____

11. **Think about the time it took you to use the product on a daily basis. In your opinion, did the product require too much time to operate?**

Yes No

PART 3

1. **What did you like MOST about the product? Please explain why.**

____

____

____

2. **What did you like LEAST about the product? Please explain why.**

____

____

____

3. **In what ways would you change the product so that you would use it more?**

____

____

____

4. **Did the product function as expected? If not, why?**

____

____

5. **Did using the product work well with your lifestyle or did you have to force yourself to use the product? Please explain.**

____

____

APPENDIX F

DATA- INITIAL PILOT EXPERIMENT

Participant ID #	Attitude Score	Behavior Score	Combined Score	Consider yourself environmentalist?	Change Score	Gender	Age	Education	Political Ideology
001	47	16	63	0	33	M	33	Senior	5
002	35	11	46	1	23	M	22	Senior	9
003	41	9	50	0	24	M	21	Senior	17
004	47	14	61	0	22	F	22	Senior	8
005	31	3	34	0	21	M	21	Senior	10
006	49	12	61		28	M	22	Senior	8
007	46	8	54	1	22	F	22	Senior	12
008	31	8	39	1	24	M	22	Senior	6
009	49	4	53	1	27	M	23	Senior	17
010	43	15	58	1	24	M	25	Senior	13
011	32	6	38	1	24	M	20	Senior	11

Condition	Recommendation	Continue to Use	Rating	Total Success score	Total success (including uses)	Favorite Product	Use Plastic Bottles	Change Habit	Difficult Set-up	Difficult Maintenance
2	4	1	4	9	13	imac	no	n/a	no	no
4	2	0	3	5	6	watch	no	n/a	yes	yes
1	2	1	5	8	10	Mac Book	no	n/a	no	no
2	2	0	3	5	6	iphone	yes	no	yes	no
3	2	1	4	7	10	laptop	no	n/a	no	no
4	2	0	4	6	7	coffee thermos	yes	no	no	no
2	2	0	5	7	11	not for sure	no	n/a	no	no
1	3	1	4	8	10	golf driver	yes	yes	no	no
2	3	0	5	8	10	g. forman grill	no	n/a	no	no
1	1	0	4	5	7	laptop	no	n/a	no	no
1	3	0	5	8	12	Britta water bottle	no	n/a	no	yes

# Uses	# Uses code	# uses code 2	Time to Learn	Like MOST
Daily	7	4	as long as it took to read directions	Portability of a water filtration system. Having the ability to improve the water I drank wherever I am is the products greatest appeal to me.
1-2 days	1.5	1	10 minutes	Interesting looking shape, nice astetics
3-4 days	3.5	2	5 min	The ability to have multiple bottles on hand
1-2 days	1.5	1	no time	I usually filter water and pour it into plastic water bottles, which takes time. The fact that I could fill it straight up with tap water and still have it filtered made it fast, east, and convenient
5-6 days	5.5	3	5-10 minutes	It was simple to set-up and "install". I gave it mostly neutral ratings because I couldn't tell much of a difference with it.
1-2 days	1.5	1	couple of minutes	It fits into the cupholder of my backpack
Daily	7	4	2 minutes	Size- easy to fit in my backpack
3-4 days	3.5	2	few minutes	it was nice that it filled into separate bottles so you can take them on the go and didn't need cups
3-4 days	3.5	2	few minutes	I can have filtered water wherever I am, easy to use and maintain
3-4 days	3.5	2	5 minutes	Multiple bottles- self contained canisters (mobile). Lids attached to water bottle
Daily	7	4	1 minute	Bottle look and feel

Like LEAST	Function as expected
I didn't like the construction of the bottle. It seemed a little thin and flimsy.	yes
Took a long time to set-up, had to read instructions	yes
How much space it took up	yes
It was difficult to actually drink. It took work to get enough water because the flow was so minimal and I had to suck really hard. As well as the cap wouldn't allow too much through it.	no- it was vey difficult to drink
Didn't seem to do that much. I like the source of my water anyway so I couldn't tell much of a difference	More or less
I just felt a little silly using it.	yes
It doesn't filter College Station Water	no- I still taste chlorine
The water filling reservior wasn't big enough to hold enough water to fill up 4 water bottles. It requires one to keep filling up the top in order to get them all full.	yes
difficult to drink out of, had to get used to it	yes
1. Would not hold enouth water to fill all bottles. 2. apparently only used small carbon pad. 3. lids interesting but confidence in them is low. 4. water tasted like plastic after stored for 2 hours (ok at first)	yes (expectations not very high)
stagnant water left over in the main filter area. With multiple people using the bottles, it could be unsanitary because the docking part touches the mouth of the bottle. Lid design was cumbersome and seemed overly complicated.	yes

Work Well with Lifestyle	Influential
Yes, I just replaced my current water bottle with this one.	No not really because I already use a re-usable water bottle.
It was not as durable as Nalgene, so I was hesitant.	No
Worked well however I did not trust the cap to stay on if I put it in a backpack	no
Had to force b/c I tend to use Smartwater bottles, which you can easily pop the top and gets lots of water	no (I am fairly eco-friendly already)
Fit into my lifestyle easily. I drink from a bottle so it was fine.	not really
It worked well as long as I remembered to bring it with me.	no
Yes, it worked well with my lifestyle. It is easy to carry around with the handle.	no
it worked well b/c I am constantly on the go so it was nice to be able to refrigerate the bottles and have them ready to go.	no
a little bit of both, it fit into my lifestyle because I sometimes carry a water bottle with me but I had to force myself to use this one instead of the other	no
Had to force it. Modular water bottles are a good idea but the stand is bulky. A collapsable base would have improved this. Drain should have hose or similar function.	not really
the bottle lid design made it difficult to put in my backpack. It also took up extra space on the counter.	no

APPENDIX G

DATA- CONSISTENT BOTTLE EXPERIMENT

Participant ID #	Attitude Score	Behavior Score	Combined Score	Consider yourself environmentalist?	Change Score	Gender	Age	Education	Political Ideology
1229-001	40	20	60	2	31	F	24	senior	7
1229-002	58	18	76	2	25	F	22	Senior	18
1229-003	53	20	73	0	28	F	18	Freshman	6
1229-004	52	16	68	0	31	F	18	Freshman	13
1229-005	56	26	82	0	32	M	21	Junior	14
1229-006	46	17	63	0	27	M	22	Senior	16
1229-007	46	11	57	1	23	M	22	Graduate	19
1229-008	59	19	78	1	31	F	19	Sophomore	11

Condition	# disposable bottles/week	Brand	Refill bottles?	non-disposable bottles?	recommendation	Continue to Use	Rating	Total Success score
1	>20	Dasani	No	Nalgene	3	0	5	8
2	0-5	Osarka, Nestle, Aquafina	yes	non-disposable water bottle and pitcher	3	1	5	9
3	6-10	ozarka, nestle, dasani	yes	insulated mug	3	1	5	9
4	16-20	ozarka	no	no	3	1	7	11
1	0-5	Great value, oxarka, Nestle	yes	yes- water bottle	4	1	6	11
3	6-10	ozarka, aquafina, store brand	yes	brita water pitcher	2	1	5	8
2	0-5	aquafina	yes	water pitcher	3	1	5	9
4	0-5	ozarka, HEB brand, Walmart brand	yes	water pitcher	2	-1	3	4

Favorite Product	# Uses	Replace disposable bottles	Difficult Set-up	Set-up time	Difficult Cleaning	Cleaning time	Too long to operate?
Nalgene	1.5	1	0	1	0	1	0
n/a	7	0	0	5	0	3	1
insulated mug	3.5	1	0	10	0	6	0
n/a	5.5	1	0	2-3	0	2-3	0
filter water bottle	5.5	1	0	2	0	2	0
Gallon refill at stores	7	0	0	5	0	5	0
n/a	7	0	0	5	0	5	0
water pitcher	7	0	0	2	0	1	0

Like MOST	Like LEAST
I loved having the filter in the product because I could fill it anywhere	The top. I like my Nalgene because I can gulp the water easily. With this squirt style bottle, it took a lot of effort to drink a little water
I don’t have to buy water bottles, therefore I save money	The pitcher doesent get rid of chlorine taste and it takes a long time to fill the pitcher
The fact that it can fit on most sinks and that you can choose to use the filtered or unfiltered water	The black stuff that came out of the filter after I initally set it up
It is a lot cheaper to use than constantly purchasing	Filling up the bottle. I am so used to just taking one out and drinking
I really like the fact that it is so easy to use and can be ready within 1-2 minutes. I have used filtered water jug which takes few minutes to get filtered water. I am satisfied with product.	Water tasted bitter than other filtered water at home
Easy set-up with clear instructions	Filtered tap water is at room temperature so had to chill in fridge or with ice. Where as with bottled water you can just grab and go
The water tastes a lot better	it takes time for the water to fill up
Simple to use in cleaning it and resetting the filtration	The water itself didn't taste as good as the pitcher I use.

What would you change?	Function as expected	Work Well with Lifestyle?	Work Well with Lifestyle- description
Give it a larger fluid oz capacity- 36 oz	yes	no	I had to force myself because I prefer to drink a lot of water per swallow and it didn't hold as much as I wished it would.
I would like it if the pitcher would get rid of the horrible taste of tap water	no- taste is still bad	no	I kind of had to force myself because I usually drink a lot of water and I don't like tap water
Try to make it small in a sense	yes	no	I had to force myself to use it since I don't drink a lot of water but since it was less hassle to use the filter than plastic water bottles, I used it more than expected
add a comfortable gripper or some sort of clip to attach to my book bag	yes	yes	Yes this product worked well
Could't ask for more.	Absolutely. I enjoyed it.	yes	It actually was the perfect product I was looking for in my bust lifestyle.
The product was classified as a filter but offered little facts about its effectiveness and/or testimonials	yes	yes	Fit in pretty well and I did have to get accostomed to it but after found that routine easy to maintain
use bigger/better filter	yes	after a while	Initially it takes time and effort to get into the practice of using the product. But, once I start using it, I don't feel like drinking out of the tap anymore
The filtration may need to be stronger	yes	yes	It worked well with my lifestyle as it was somple and fast to use

Interview Question
I didn't care for it overall because I like the open bottle mouth better. I did however like that I could fill it up anywhere, it was BPA free, and it was easy to clean.
I didn't really like it overall because it didn't get rid of the bad taste of the water.
Overall, she liked it and her roommate also liked it. One thing she didn't like was that she lives in a dorm room and it was kinda difficult to fill up the water bottle in her small sink.
Overall I liked it because it is a cheaper option than always buying plastic water bottles. It was good at eliminating the bad taste of tap water.
Yes overall I liked it because it was simple to use and the time to operate was very short
Overall, yes. It was easy to set up. Only bad thing was that water was at room temp and had to add ice if wanted cold water.
Yes, he enjoyed it. It took some time to get used to but after some time he developed a habit of using it.
Overall she did not like it. It did not filter the water as good as her water pitcher. It was however easy to use, but ultimately that did not matter because the taste of the water was more important.

APPENDIX H

PAPER TOWEL EXPERIMENT- DATA COLLECTION SHEETS

Paper Towel Correlation Sheet

Weight (g)	Radius (in)	Length removed (in)

Weight (g)	Radius (in)	Length removed (in)

WEEK: ____________________

	Date:		**Date:**	
	Original weight	**Original Radius**	**Final Weight**	**Final Radius**
Bathroom A				
	Original weight	**Original Radius**	**Final Weight**	**Final Radius**
Bathroom B				
	Original weight	**Original Radius**	**Final Weight**	**Final Radius**
Bathroom C				

APPENDIX I

PAPER TOWEL EXPERIMENT- CORRELATION DATA

Data set 1:

Weight (g)	Radius (in)	Length Removed (in)	Length on Roll (in)	Predicted length based on weight	Difference (in)	% difference
2065.300	2.864	0.000	8373.000	8369.922	-3.078	-0.037%
1963.600	2.736	420.000	7953.000	7952.891	-0.109	-0.001%
1876.900	2.623	357.000	7596.000	7597.369	1.369	0.018%
1790.400	2.583	355.000	7241.000	7242.667	1.667	0.023%
1703.500	2.485	355.000	6886.000	6886.325	0.325	0.005%
1617.000	2.403	355.000	6531.000	6531.623	0.623	0.010%
1530.000	2.307	355.000	6176.000	6174.871	-1.129	-0.018%
1443.300	2.213	355.000	5821.000	5819.349	-1.651	-0.028%
1357.000	2.143	355.000	5466.000	5465.467	-0.533	-0.010%
1270.800	2.054	355.000	5111.000	5111.995	0.995	0.019%
1184.700	1.984	355.000	4756.000	4758.934	2.934	0.062%
1098.000	1.872	355.000	4401.000	4403.412	2.412	0.055%
1010.900	1.790	355.000	4046.000	4046.250	0.250	0.006%
923.600	1.662	355.000	3691.000	3688.267	-2.733	-0.074%
749.100	1.466	715.000	2976.000	2972.712	-3.288	-0.110%
574.900	1.194	715.000	2261.000	2258.388	-2.612	-0.116%
400.200	0.887	715.000	1546.000	1542.013	-3.987	-0.258%
232.200	0.496	715.000	831.000	853.112	22.112	2.661%
139.700	0.299	355.000	476.000	473.807	-2.193	-0.461%
52.900	0.083	355.000	121.000	117.875	-3.125	-2.583%
22.100	0.000	121.000	0.000	-8.424	-8.424	#DIV/0!

Data set 2:

Weight (g)	Radius (in)	Length Removed (in)	Length on Roll (in)	Predicted length based on weight	Difference (in)	% difference	Predicted length based on radius	Difference	% difference
2102.300	2.895	0.000	8440.000	8454.273	14.273	0.169%	8552.829	112.829	1.337%
1913.500	2.673	768.000	7672.000	7686.254	14.254	0.186%	7511.570	-160.430	-2.091%
1630.600	2.433	1152.000	6520.000	6535.445	15.445	0.237%	6453.817	-66.183	-1.015%
1618.800	2.373	48.000	6472.000	6487.444	15.444	0.239%	6203.826	-268.174	-4.144%
1524.400	2.317	384.000	6088.000	6103.434	15.434	0.254%	5970.735	-117.265	-1.926%
1383.000	2.188	576.000	5512.000	5528.233	16.233	0.294%	5456.189	-55.811	-1.013%
1379.800	2.187	12.000	5500.000	5515.215	15.215	0.277%	5450.311	-49.689	-0.903%
1096.000	1.866	1152.000	4348.000	4360.745	12.745	0.293%	4261.894	-86.106	-1.980%
1014.500	1.815	336.000	4012.000	4029.212	17.212	0.429%	4085.203	73.203	1.825%
777.400	1.512	960.000	3052.000	3064.712	12.712	0.417%	3105.751	53.751	1.761%
730.000	1.449	192.000	2860.000	2871.894	11.894	0.416%	2917.214	57.214	2.001%
682.500	1.373	192.000	2668.000	2678.669	10.669	0.400%	2696.698	28.698	1.076%
634.900	1.310	192.000	2476.000	2485.037	9.037	0.365%	2519.640	43.640	1.763%
626.300	1.268	36.000	2440.000	2450.053	10.053	0.412%	2404.492	-35.508	-1.455%
436.200	0.975	768.000	1672.000	1676.745	4.745	0.284%	1664.363	-7.637	-0.457%
341.200	0.778	384.000	1288.000	1290.294	2.294	0.178%	1230.911	-57.089	-4.432%
329.300	0.755	48.000	1240.000	1241.886	1.886	0.152%	1184.642	-55.358	-4.464%
139.500	0.323	768.000	472.000	469.799	-2.201	-0.466%	424.961	-47.039	-9.966%
44.500	0.077	384.000	88.000	83.349	-4.651	-5.286%	102.024	14.024	15.936%
22.100	0.000	88.000	0.000	-7.772	-7.772	#DIV/0!	16.788	16.788	#DIV/0!

APPENDIX J

PAPER TOWEL EXPERIMENT- WEIGHT & RADIUS DATA

Week 1

Bathroom A	**Original weight**	**Original Radius**	**Original Length**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	0	0	16 inches	Short- 8 in.	xxxxxx	xxxxxx	xxxxxxx	xxxxxx
Bathroom B	**Original weight**	**Original Radius**	**Original Length**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2112.8	2.8863	16 inches	Medium- 12 in.	1665.66	2.4842	447.14	0.4021
Bathroom C	**Original weight**	**Original Radius**	**Original Length**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2044.98	2.9344	8 inches	Long- 16 in.	1429.84	2.269	615.14	0.6654
Bathroom D	**Original weight roll 1**	**Original Radius roll 1**	**Original weight roll 2**	**Original Radius roll 2**	**Original Length**	**Final Length**	**Final Weight roll 1**	**Final Radius roll 1**
	2145.62	2.8991	2066.22	2.8695	16 inches	Short- 8 in.	439.02	0.9321
Bathroom E	**Original weight**	**Original Radius**	**Original Length**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	0	0	16 inches	Medium- 12 in.	xxxxxx	xxxxxx	xxxxxxx	xxxxxx
Bathroom F	**Original weight**	**Original Radius**	**Original Length**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2106.36	2.8929	16 inches	Long- 16 in.	1053.9	1.7901	1052.46	1.1028

Final Weight roll 2	Final Radius roll 2	Change in Weight	Change in Radius
607.9	1.2417	3164.92	3.5948

Week 2

Bathroom A	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	1999.12	2.8329	Medium- 12 in.	1161.36	2.1075	837.76	0.7254
Bathroom B	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2114.06	2.8985	Long- 16 in.	1697.38	2.5106	416.68	0.3879
Bathroom C	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2107.8	2.9205	Short- 8 in.	1566.5	2.3727	541.3	0.5478
Bathroom D	**Original weight roll 1**	**Original Radius roll 1**	**Original weight roll 2**	**Original Radius roll 2**	**Original Length**	**Length**	**Final Weight roll 1**
	2109.08	2.8361	2104.44	2.8804	16 inches	Short- 8 in.	255.3
Bathroom E	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2112.88	2.914	Long- 16 in.	852.82	1.5519	1260.06	1.3621
Bathroom F	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2101.1	2.8621	Short- 8 in.	1205.26	2.0173	895.84	0.8448

Final Radius roll 1	Final Weight roll 2	Final Radius roll 2	Change in Weight	Change in Radius
0.6159	23.66	0.1243	3934.56	4.9763

Week 3

Bathroom A	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2136.5	2.914	Long- 16 in.	1046.64	xxxxxxx	1089.86	xxxxxx
Bathroom B	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2129.98	2.9087	Short- 8 in.	1661.94	xxxxxxx	468.04	xxxxxx
Bathroom C	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2125.16	2.8771	Medium- 12 in.	1596.58	xxxxxxx	528.58	xxxxxx
Bathroom D	**Original weight roll 1**	**Original Radius roll 1**	**Original weight roll 2**	**Original Radius roll 2**	**Original Length**	**Length**	**Final Weight roll 1**
	2142.48	2.8586	2090.88	#DIV/0!	16 inches	Short- 8 in.	xxxxxx
Bathroom E	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2111.56	2.9387	Short- 8 in.	522.5	xxxxxxx	1589.06	xxxxxx
Bathroom F	**Original weight**	**Original Radius**	**Length**	**Final Weight**	**Final Radius**	**Change in Weight**	**Change in Radius**
	2101.28	2.7472	Medium- 12 in.	1219.68	xxxxxxx	881.6	xxxxxx

Final Radius roll 1	Final Weight roll 2	Final Radius roll 2	Change in Weight	Change in Radius
xxxxxx	xxxxx	xxxxxx	xxxxxx	xxxxxx